

*Report
of the
Joint Advisory Committee
on Foundry Goggles*



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CONTENTS

	Page
Membership of Joint Advisory Committee on Foundry Goggles	vi
List of Former Members	vi
 INTRODUCTION	 1
General Considerations	2
Standard of Protection	3
Basis of Tests	4
Scope of the Tests	5
 TEST EQUIPMENT	 5
Preliminary Trials	5
Low Velocity Ballistic Equipment	6
High Velocity Ballistic Equipment	7
The Testing of Materials	7
The Testing of Goggles	7
Burning Tests	8
Needle Tests	8
 RESULTS	 8
Materials	8
Wire Mesh	8
Glass	9
Plastic Materials	10
Goggles	11
Spectacles	11
Cup Type Goggles	11
Visor Type Goggles	12
Face Screens	12
 OPTICAL PROPERTIES	 12
Light	12
Ultra-Violet	13
Infra-Red	13
Total Heat	13
Protection Against Infra-Red	13
 MISTING	 14
 DURABILITY	 14
 COMFORT	 14
 IMPACT GOGGLES	 15
 CONCLUSIONS	 15
 RECOMMENDATIONS	 16
 ACKNOWLEDGMENTS	 17

APPENDICES

	Page
I First Interim Reports of the Joint Advisory Committee and of the Sub-Committee of the Joint Advisory Committee	19
II A Report on a Laboratory Ballistic Trial of Goggle Lenses by A. M. Reid, B.Sc.	56
III Second Interim Reports of the Joint Advisory Committee and of the Sub-Committee of the Joint Advisory Committee	71
IV Third Interim Reports of the Joint Advisory Committee and of the Sub-Committee of the Joint Advisory Committee	103
V Fourth Interim Report of the Sub-Committee of the Joint Advisory Committee	123
VI Fifth Interim Report of the Sub-Committee of the Joint Advisory Committee	136
VII References	144

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Mr. T. A. Swinden, Engineering and Allied Employers' National Federation
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TRADE UNION REPRESENTATIVES

Mr. J. Higham, M.B.E., National Union of Stove, Grate and General Metal Workers
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LIST OF FORMER MEMBERS

Mr. T. W. McCullough, C.B., O.B.E., H.M. Chief Inspector of Factories	Chairman	1955-1956
Mr. R. Bramley-Harker, H.M. Deputy Chief Inspector of Factories	Chairman	1956-1960
Mr. W. A. Attwood	Secretary	1955-1957
Mr. F. Bullock	Member	1960
Professor G. P. Crowden	Member	1955-1963
Mr. G. T. Hyslop	Member	1955-1957
Mr. F. A. W. Livermore	Member	1955-1957
Dr. A. I. G. McLaughlin	Member	1955-1959
Dr. R. G. Sarjant	Member	1955-1956
Mr. H. C. Weston, O.B.E.	Member	1956-1960

REPORT OF THE JOINT ADVISORY COMMITTEE ON FOUNDRY GOGGLES

*Mr. R. K. Christy,
H.M. Chief Inspector of Factories*

INTRODUCTION

1. In 1955 H.M. Chief Inspector of Factories invited representatives of the Employers Federations, the Trade Unions, the British Standards Institution, the Medical Research Council and certain Universities and Research Organisations to form a Committee to advise him on some aspects of the use of goggles in the founding industry. The Committee held its first meeting in October 1955, with the following terms of reference:

"To advise H.M. Chief Inspector of Factories as to the most efficient type of eye protection to be worn by a foundry worker at risk from molten metal".

2. We have held twenty-one meetings and, during the course of our work, we have examined an analysis of all the accidents to eyes that occurred in the founding industry in 1954 and 1956, we have visited three foundries, we have had the literature searched for work done in this country and overseas, we have held discussions with interested individuals, firms and other organisations, and research and development work has been initiated and carried out on certain aspects of the problem presented to us. We consider that we have completed our task and we are therefore presenting our Report to you. The design of equipment for the protection of eyes, however, needs constant attention and, as new materials become available, they should be examined and used if they show any advantages. Our own work has of necessity been somewhat empirical in nature and more systematic work would no doubt extend knowledge over aspects of the problem which we did not explore experimentally because we thought they had no immediate relevance. We hope therefore that you will see fit to publish this Report so that those who manufacture and those who use equipment for the protection of the eyes may be fully informed of the present position and may be induced to continue the development work which we began in a persistent effort to improve all types of equipment which is used to prevent injuries to eyes.

3. We found in 1955, one American Report,¹ but apart from this we discovered no other published work that would assist us and so we decided to do our own experimental work. We set up a Sub-Committee for this purpose consisting of Mr. G. T. Hyslop, Mr. A. W. Bushell and Mr. W. B. Lawrie, and gave them powers to co-opt. Mr. Hyslop resigned from this Sub-Committee in March 1957 and Dr. S. G. Rainsford was appointed in March 1962.

4. The Sub-Committee has now completed a large amount of work and its results are presented in Appendices I, III, IV, V and VI. These Appendices are essentially Sub-Committee Reports although Appendices I, III and IV also contain the short covering report which we added for the purpose of publishing the work as interim reports in the technical press. This work was published ^{2, 3, 4} because

we thought, and H.M. Chief Inspector of Factories agreed, that both the founding industry and that part of the optical industry concerned with goggles should be informed of the progress that was being made in these difficult and somewhat protracted investigations. We also published as an Appendix to the first of these interim Sub-Committee Reports (see Appendix II) a record of work done on the protection of eyes in circumstances different from those in foundries because we thought that associated work done in other fields could not fail to be useful in a subject in which there was so little published information when we began our deliberations.

General Considerations

5. Certain general comments seem to be desirable before we proceed to a discussion of our main work. Perhaps the most important of these is that while goggles and other types of personal protective equipment for the eyes may prevent injuries they never prevent accidents. The initial causes which result in molten metal being splashed, or projected across a foundry are often accidents which should have been avoided and these causes should be dealt with as matters of general safety. For instance, good lighting and clear unobstructed floors are essential if men carrying molten metal in hand ladles are not to stumble. Ladles should not be over-filled, ingates should be sufficiently far from the edges of the moulding boxes to allow some latitude for slight inaccuracy in pouring molten metal from hand shanks and so on. These matters are not our concern in this report but we are concerned that goggles should be expected to protect only from injury and not be expected to replace other general safety measures.

Similarly, goggles should not be used alone to prevent injury if other means of protection can be used as well. For example, centrifugal machines should be provided with adequate metal guards to contain molten splashes which may be thrown off because these guards can be much more robust and much heavier than goggles which must, of necessity, be light enough and small enough to wear.

6. The founding industry uses a great variety of melting and casting methods, and a wide range of metals with very different melting points. The requirements of goggles in the different sections of the industry vary therefore and what may be suitable for one section of the industry may not be as suitable for another. We think that these different requirements can be met in a relatively small number of types of goggles, but the diversity of the industry has not made our task any easier.

7. The design and construction of goggles is a somewhat complicated matter because they must be of adequate strength to resist impact, of suitable material to withstand molten metal, light in weight, comfortable, well ventilated to avoid "misting", durable, with a high transmission value for wave lengths within the visible spectrum and, if necessary, absorbent to other wave lengths which may be injurious to the eyes. All these requirements can be met but it is no easy matter to meet them all in one pair of goggles.

8. Finally, there are questions of individual preference which must not be disregarded if men are to be expected to wear goggles for long periods of time. For this reason different types are essential even though they may offer equivalent protection.

The difficulty of making specific and simple recommendations is evident enough from these considerations and there must be some flexibility of choice in any particular circumstances. Nevertheless, we think we should now report to you the information that we have obtained during the life of the Committee and put before you such recommendations as we can draw from this information while still allowing that freedom of choice on which we have already remarked.

9. Throughout this report and as a matter of convenience we have used the word "goggles" to include all types of personal protective equipment for the eyes except in those instances in which it has been necessary to distinguish between these types.

10. One further general point requires attention. During our work on goggles for the protection of men at risk from molten metal, we have designed new goggles and found new materials which provide a high standard of protection against impact. This standard is so very much in excess of anything hitherto known that we think it right to draw your attention to it because it might be applied to goggles used by men who are not at risk from molten metal and who are, in consequence, outside our terms of reference. We are informed that the British Standards Institution has a Committee which is considering the possibility of a new British Standard as a consequence of our work, which may thus be made available to a much greater range of industry than that with which we are concerned. We have noted too that in the revised British Standard 2092: 1962 a warning has been included in the following terms:—

"Consequent upon the publication of the various reports of the Ministry of Labour Joint Advisory Committee on Foundry Goggles it is necessary to emphasize that industrial eye protectors complying with the requirements of this Standard are not intended to withstand the test blows used in the J.A.C. method of test.

Until publication of the additional specification referred to above reference should be made to the findings of the J.A.C. when considering protection against flying molten metal or other high-speed impact."

Standard of Protection

11. We accepted our Sub-Committee's argument and conclusions on the desirable standard of protection and the kinds of tests that were necessary. Their discussion will be found in detail in Appendix I, but it is for convenience summarised here.

The degree of protection that is required of goggles can only be defined by stating that if a man survives an accident then his goggles should have been good enough to preserve his eyes. This is obviously an ideal and at the beginning of the work it was not known whether or not it could be attained. It is now known that equipment for the protection of the eyes can be made, and made relatively simply, to withstand molten metal and also to withstand the impact of a solid spherical projectile of steel, weighing approximately 1 gram, and striking at a velocity of 500 ft. per second (about 340 miles per hour). Such an impact on any part of the face or head would cause very serious injury even if it did not prove fatal, so that it appears that the ideal degree of protection as defined may well be within the range of practicability.

12. So far we have discussed only the ability of the goggles to withstand molten metal moving at high velocity. Other matters, such as the durability of the goggles, light transmission, internal reflexion, the ability to absorb infra-red radiation and weight, cannot be ignored; but the ability to resist molten metal at the velocities that might be expected in foundries is paramount because it is manifestly useless to discuss these other properties if eyes cannot first be protected from physical destruction by molten metal which has penetrated the goggle lens.

Basis of Tests

13. Our Sub-Committee decided to develop their own test appliances because no adequate methods of testing could be found in the published literature. Once again we agree with the arguments and conclusions on which they finally designed the appliances and we summarise them here as a matter of convenience.

Ideally, any appliance for testing materials or goggles should be capable of penetrating every specimen because the practice of testing to destruction enables all the materials and goggles so tested to be placed in order of merit. It also allows some estimate to be made of the factor of safety that is allowed when selecting a particular pair of goggles for a particular use. But, since materials have been found and goggles made which will withstand spherical projectiles weighing about 1 gram at velocities in excess of 340 miles per hour, it has not proved possible to test to destruction although we still think that this should be done.

14. Another method of testing is to take a specified impact value (or a specified weight of projectile and a specified velocity) and use this as a suitable standard. The difficulty in this method lies in the selection of the standard because it is not possible to define what might be called "average risk". Very occasionally a mould explodes and large quantities of molten metal may be thrown violently into the air. On the other hand, very small splashes occur when no more than a fraction of a gram of metal may be projected into the air. It cannot be said, therefore, that any selected weight would be the average weight against which protection might be needed. Neither is it possible to define average velocity at which splashes of molten metal move across a foundry. Under the disruptive pressure which causes a mould to explode the splashes obviously travel at high speed, while splashes originating from spillage from a hand ladle move quite slowly. Because average weight and average velocity cannot be defined, average momentum also remains unknown.

15. Finally the Sub-Committee selected a speed which was known to occur within the industry even though it was not in the foundry where molten metal would be present, but in the dressing shop. Cut-off wheels may work at peripheral speeds up to 20,000 ft. per minute. When such a wheel breaks, fragments are projected at an initial velocity equal to the peripheral velocity of the wheels so that here is a known speed of about 225 miles per hour which may occur within the industry. The selection of this speed does not imply any estimate of the speeds that might be encountered from flying molten metal splashes. It was merely chosen as an empirical starting point from which appliances and machines might be designed for the purpose of testing both materials and goggles. About the time that these decisions were being made, the Sub-Committee were allowed to see some original work which had resulted in a new kind of goggle which

would withstand the impact of a cube of steel weighing about 1 gram, and moving at 850 ft. per second (i.e. about 600 miles per hour). These goggles, however, were not suitable for industrial use (see Appendix II) and so no attempt was made to reach such a high velocity. Later in the work suitable goggles were constructed from a material discovered by the Sub-Committee which would withstand velocities of 500 ft. per second, so that the requirements of the original empirical standard have now been exceeded, but these possibilities were not known when the lower velocity of about 330 ft. per second (20,000 ft. per minute) was chosen. In any case, the selected velocity was so far in excess of any test that had been applied to goggles in the past as to be in another order of magnitude.

16. Because of the work to which reference has just been made, it was decided that the projectile should be comparable in weight so that results might also be comparable. This ultimately led to a use of $\frac{1}{4}$ inch diameter steel ball bearings as projectiles.

Finally the Sub-Committee decided that no method should be used for testing that could not be calibrated in terms of the energy expended in the test.

Scope of the Tests

17. Splashes of metal which leave their point of origin in the molten state will change continuously in temperature and oxidise as they pass through the atmosphere. So that a man who is at risk from molten metal may be struck by a molten splash of metal, by a hot solid piece of metal or by a spark which may virtually be metallic oxide. The terms of reference refer specifically to "a foundry worker at risk from molten metal" but clearly such a man may also be struck by solidified metal or by metal oxides even though he may properly be said to be "at risk from molten metal". It has, therefore, been necessary for the Sub-Committee to diverge from the terms of reference in order to meet them because goggles could not be considered suitable unless they were adequate against both molten metal and solid projectiles.

18. A further reason for the large amount of work that has been done by the Sub-Committee on the impact properties of goggles lies in the fact that flying liquid metal is possessed of kinetic energy as well as heat. So that impact properties cannot be disregarded in goggles which are designed to resist molten metal. A more trivial point was that earlier standards had been made on the basis of impact tests so that new types could only be compared with old types by a comparison of their properties in impact.

19. All the work that was done by the Sub-Committee was, therefore, quite essential, and even the cold impact tests, which might at first sight appear to be remote from the question in the terms of reference, were done to ensure that any recommended form of personal equipment for the protection of eyes would, in fact, protect "a foundry worker at risk from molten metal".

TEST EQUIPMENT

Preliminary Trials

20. No suitable equipment was available for the testing of materials or goggles so that the Sub-Committee had first to devise methods of testing, and then design and construct their own equipment. This work is described in detail in the Appendices to this Report and so no more than a summary will be given here.

21. A few practical tests were done in the early stages on a production centrifugal casting machine in which phosphor bronze was being cast at a temperature of about 1,150°C. The mould, which was rotating about a horizontal axis, was slightly over-filled so that there was a splash of molten metal at the front opening. Goggles mounted on cardboard were held in this splash and some of them, notably wire mesh goggles, were penetrated by the metal. Further tests were done by dropping molten metal on to a rotating table and mounting goggles in the stream of sparks so emitted, but the method was discarded because it was hardly possible to calibrate the machine.

22. A standard test rig was also constructed to the specification given in British Standard 2092: 1954 and some materials were tested in this equipment even though the test was so far below that visualised by the Sub-Committee as not to be comparable. One interesting result of this part of the work was that glass specimens which would pass this test, applied as described in the Standard, frequently failed if they were mounted in a solid steel ring. This suggested that the glass specimens mainly passed the test on account of the resilience in the mounting, but that the factor of safety above the test was so slight that if this resilience were removed, the glass would fail the test.

This equipment was also fitted with a steel dart of the same weight as the $\frac{7}{8}$ inch diameter ball bearing so that the effects of impact by a pointed projectile could also be determined.

Low Velocity Ballistic Equipment

23. The Sub-Committee then designed and constructed a spring-loaded low velocity ballistic machine in which molten metal from a dish could be projected at specimens of different materials (see Appendix I). The velocity of the molten projectile did not much exceed 9½ ft. per second (compared with the British Standard 2092 velocity of about 6.4 ft. per second). The machine was so arranged that three different weights of any molten metal could be used as projectile, and if iron were the metal, these weights were respectively 35 grams, 95 grams, and 145 grams. As the recess in the machine from which the molten metal was projected determined the volume of the charge, other metals gave different weights.

24. The specimens which were used for testing were circular and two inches in diameter. They were mounted solidly in metal retaining rings so that there was no resilience in the mounting. A variety of materials was tested, including toughened glass, laminated glass, methyl methacrylate, cellulose acetate, a polycarbonate and a co-polymer which was essentially a rigid polyvinyl. The materials were tested against white metal, aluminium, phosphor bronze, Admiralty gun metal, stainless steel and cast iron, all in the molten state.

Tests were also made on this equipment using cold, solid projectiles (i.e. ball bearings of different sizes).

25. The work on the low velocity ballistic equipment showed that glass always cracked on impact with molten metal and that plastic materials were frequently undamaged. It was evident that the effects of heat and impact could be separated because, however light the blow, the glass specimens always cracked, the molten metal adhering to them so that the rapid expansion following the heat transfer from projectile to specimen cracked the glass. Plastic specimens were

never damaged by the heat of the projectile. This appeared to be due to the fact that the molten metals used did not adhere to the plastic specimens but splashed away from them. The time of contact between molten metal projectile and plastic specimen was therefore so small that there was virtually no transference of heat and so the specimen remained undamaged.

High Velocity Ballistic Equipment

26. Clearly, heat transfer is a function of time. With a glass specimen and adhering molten metal, this time is the time taken for the projectile to cool. With plastic specimens this time is very short (being a function of the speed of the projectile) because, so long as the specimen withstands the impact of the blow, the faster the projectile strikes, the faster will it rebound. This means that, so far as the effects of heat are concerned, high speed molten projectiles will do less damage to plastic specimens than will low speed projectiles, the heat transferred from projectile to specimen increasing as the projectile velocity decreases. That is to say, that the most severe tests result from the lowest velocities so far as heat is concerned. But the early low velocity tests indicated that the plastic specimens would withstand the molten projectiles. Once it was known that the plastic materials would withstand the heat in the more severe conditions of these low velocity tests there was no point in testing under the less severe conditions of high velocity tests so far as the effects of heat were concerned. This argument is valid for molten metal projectiles and for hot solid projectiles so long as the latter bounce off the specimen after impact. It is not valid if hot solid projectiles embed themselves into a specimen when the impact has been insufficient to break it. For this reason the Sub-Committee did further work on the influence of heat on plastics in a series of burning tests which are mentioned in paragraph 30.

27. The foregoing considerations led to the view that impact tests could be done with cold solid projectiles so long as other tests had provided sufficient information about the effects of heat as distinct from the effects of impact. The Sub-Committee therefore proceeded to the use of cold, solid projectiles because there was no point in using molten metal for impact testing.

The Testing of Materials

28. The equipment described in Appendix III was designed and constructed for the testing of specimens of different materials. The air rifle was modified to project a $\frac{1}{2}$ inch diameter steel ball bearing at a velocity of 390 ft. per second, this speed being increased at a later stage of the work to 500 ft. per second, and toughened glass, laminated glass and a variety of plastic materials were tested.

The Testing of Goggles

29. When materials had been found that would withstand the high velocity impact test a second rig was designed and constructed by the Sub-Committee so that goggles, visors and face shields could also be tested. This equipment is described in Appendix IV and a variety of goggles was designed, constructed and tested at velocities of 390 ft. per second, and 500 ft. per second, until successful goggles were found.

Burning Tests

30. The effect of heat on plastic specimens has already been discussed when molten metal projectiles are used and when hot, solid projectiles bounce away from the specimens on impact. But if such a hot, solid projectile were to embed itself in a lens which the impact had not broken, the heat from the projectile would be transferred to the plastic material and would damage it—damage it that is, in addition to the damage already resulting from the impact. It is obviously a matter of some importance that lenses with a hot, solid projectile embedded in them should neither take fire nor melt in so short a time that the wearer would be unable to remove the goggles from his face before suffering injury. The Sub-Committee therefore designed and constructed apparatus to determine the effects of heat on plastic specimens in these conditions and this apparatus is described in Appendix III.

Needle Tests

31. The Sub-Committee also designed and constructed a machine in which it was possible to submit specimens of materials to impact from a needle. The machine which was calibrated and used on glass and plastic specimens which were all two inches in diameter, is described in Appendix I.

RESULTS

32. The results of some hundreds of tests on a variety of materials and goggles are given in detail in the Appendices of this Report, but a broad summary of these results is necessary here in order to support the discussion that follows.

Materials

33. The Sub-Committee began by testing materials because there seemed to be little point in constructing or testing goggles until the reactions of the materials had been determined by the new tests. The materials which were tested included wire mesh, toughened glass, laminated glass and plastics. Among the plastics were an allyl resin, methyl methacrylate, a co-polymer which was essentially a rigid polyvinyl chloride, and a cellulose acetate.

Wire Mesh

34. The early work indicated that molten metal was liable to penetrate wire mesh if the metal were moving at the velocities at which it might leave a centrifugal mould. We appreciated that wire mesh goggles might be comfortable to wear, might not impede vision, would not mist in the thermal conditions of a foundry, and were light in weight. But because none of these advantages overcame the single disadvantage that they do not offer protection against molten metal, we think that wire mesh should not be used to protect eyes in these circumstances.

35. In the early stages of the work we rejected the use of wire mesh in any other form than as side pieces. But in later work, plastic goggles to which wire mesh ventilators had been fitted were tested against molten metal. The molten metal adhered to the cold metal of the wire mesh and cooled there in contact with the plastic, and the heat from this cooling metal was sufficient to burn or melt some of the plastic materials. This led us to the conclusion that goggles should neither be mounted in metal rims nor should they be ventilated through

any form of metal mesh. In fact, because molten metal tends to adhere to cold metal, no exposed metal should be used in the construction of goggles which are to be used to protect men against molten metal.

Glass

36. Glass may give protection against very light sparks and splashes but it was found that the glass specimens were always broken in the conditions of the tests that were applied. The lightest blow with the smallest quantity of any of the molten metals used broke all the glass specimens (see Appendix I). This was because the molten metal adhered to the glass which was broken by the rapid transference of heat even if it were not broken by the impact. The toughened glass lenses were shattered and the laminated lenses badly cracked. Apart from the hazard of the molten metal itself, a secondary hazard was created by reason of the fact that splinters of glass were thrown off that side of the specimen which was remote from the side receiving the impact of the molten metal. If the specimens had been in use as goggles, therefore, these splinters would have been thrown off from the side of the lens which would have been adjacent to the eye of the wearer and they would have been moving in the direction of his eye (see Appendix I).

37. All the glass specimens were broken by the needle tests and by the cold impact test when the $\frac{1}{2}$ inch diameter spherical projectile was used (see Appendices I and III). It was also known from the preliminary work that the glass lenses would frequently fail under the impact of the large ball described in British Standard 2092 if the lenses were mounted solidly and so deprived of the resilience provided by that test as normally performed. This meant that glass lenses barely reached the higher standard of the two prescribed by British Standard 2092, there being very little margin of safety.

38. Impact testing accentuated the secondary hazard due to the shower of splinters which was projected from the side of the glass which would be nearer to the eye of the wearer (i.e. the surface remote from the one that received the blow). This effect was noticeable from the low velocity tests done with the rig which conformed to the British Standard 2092 specification, and much more evident from tests done at 390 ft. per second. It is also of interest to note that this secondary hazard was observed in the independent work which was done at still higher impact speeds, and which is described in Appendix II.

39. Both toughened and laminated glass specimens therefore failed all the Sub-Committee's tests both against molten metal projectiles and against cold, solid projectiles. Toughened glass was shattered, the fragments being driven back towards the eye of the wearer at high velocity. Laminated glass specimens were either cracked, when they delivered splinters from the back surface in the direction of the eye of the wearer, or were shattered like the toughened lenses when the fragments were again driven back towards the eye of the wearer.

40. It may be true that glass goggles will protect against small splashes or against very light splashes. But in view of the work of the Sub-Committee we could no longer say that glass (either toughened or laminated) offered protection to men at risk from molten metal.

Plastic Materials

41. The work with molten metal projectiles showed at once that plastic materials were greatly superior to glass in their resistance to molten metal; in fact, it would be generally true to say that the plastics tested, so long as they exceeded 0.010 inches in thickness, were not penetrated by any of the molten metal projectiles used on the machine (see Appendix I). Molten metal does not appear to wet plastic surfaces so that it does not adhere to them. In consequence, the amount of heat transferred from the molten projectile as it strikes the surface of the plastic is negligible. Unlike glass, therefore, the plastic specimens were not damaged by heat. Molten metal does adhere to cold metal and it is for this reason that we have already remarked that the plastic materials should not be mounted in metal rims, fitted with metal mesh or gauze for ventilation, or associated in the construction of the goggles with any exposed metal parts.

42. Plastic materials also withstood the impact of red hot solid projectiles (see Appendix I) and that of the needle test (Appendix I) and gave satisfactory results on the burning test (Appendix III).

43. The Sub-Committee then proceeded to the testing of plastic specimens under the impact of cold solid projectiles at both 390 ft. per second and 500 ft. per second. Different plastics reacted differently to these tests which are described in detail in the Appendices III and V.

The general result of this work was the production of plastic lenses which would withstand the tests. It appeared that laminated lenses or lenses with two layers were better than plastic lenses of one piece. These latter were not so good against impact so that it seems that thickness is not in itself a sufficient criterion of strength against impact. Only one laminated plastic lens was successful against the impact test at 390 ft. per second, and there was some danger from these laminated plastic lenses that fragments might fly from the surface which would be adjacent to the eye of the wearer.

44. Double acetate lenses were found which withstood molten hot metal and needle tests, and resisted cold impact when the projectile was moving at 390 ft. per second. These lenses consisted simply of two layers of acetate placed together, the thinner layer receiving the blow during the test. The two layers were not stuck together in any way and so they were called "double lenses" to distinguish them from true laminated lenses in which the two layers are held together by an adhesive. The first satisfactory lens consisted of a thinner acetate layer which was 0.050 inches thick, backed by a thicker one of 0.080 inches thick. At a later stage it was found that the double acetate lens might equally well consist of layers, each of which were 0.080 inches thick. This might have some practical advantage in that it would be impossible to mount the lenses the wrong way round.

45. A series of tests was done by the Sub-Committee on double lenses which had been made from material containing internal stresses. Difficulty was experienced in getting the thinner material (0.050 inches thick) in a stressed condition, but the thicker acetate sheet (0.080 inches thick) was more readily obtained in this state. The results showed that lenses made of material containing internal stresses were significantly weaker than unstressed lenses. Stresses can easily be detected by examining the material in polarised light and all lenses should be so examined, the stressed material being discarded.

46. Other tests indicated that the presence of liquid had no recognisable effect if it were present on the front face or the back face (or both) of a double lens, but that it did reduce the impact value if there were a continuous film of liquid between the lenses, so producing what was virtually a liquid laminated lens.

47. Finally, a polycarbonate plastic material was found which could be used in a single thickness of 2 millimetres (approximately 0.080 inches). This material withstood all the tests and was not penetrated or cracked when submitted to a cold impact test in which the projectile was moving at 500 ft. per second (see Appendix V). Even at this high speed, and with twelve shots on the same spot, the material was so far below its limit that the effect of strain appeared to be insignificant.

48. There can be no doubt therefore that plastics are greatly superior to glass in withstanding molten metal and impact, and that easily available plastic materials will give complete protection against the severe tests that our Sub-Committee has devised and applied. In fact the range of protection that can be provided by plastic materials is so greatly in excess of that offered by laminated or toughened glass that so far as these aspects of the matter are concerned, glass can be ignored.

Goggles

49. The Sub-Committee having found suitable materials then proceeded to consider the design and construction of goggles. In this part of the work they were no longer testing the strength of a material but the resultant of material strength, constructional strength, resilience due to design, movement on impact, and so on. The term "goggles" has been used to indicate all types of personal equipment worn to protect the eyes. As the problem now was that of mounting the lenses so that they would not be driven out of the goggles by the impact of the projectiles, different types of goggles were examined separately so that each type must now be distinguished by its own name. We used the word "Spectacles" in its ordinary sense to describe the article shown in Fig. 1, "Cup type goggles" as shown in Fig. 2, "Visor type goggles" in Fig. 3, and a "Face screen" in Fig. 4.

Spectacles

50. The Sub-Committee did a few tests on spectacles (Appendix IV) but it appeared that there might be some difficulty in making spectacles sufficiently strong to withstand the impact test; for instance, the lenses might be driven out of the frames, or the frames might be broken. It also appeared that high impact tended to knock the spectacles off the face of the wearer. For these reasons, and because of the fact that other types were more easily developed, very little work was done on spectacles.

Cup Type Goggles

51. The Sub-Committee then examined cup type goggles, deciding after early tests to adapt a standard type of goggle which was made of clear cellulose acetate. This was fitted with the selected double lenses and further testing showed that these lenses should be seated on a polyvinyl chloride washer and held in position with a nylon ring. An exploded view of the goggles is given in Fig. 24 (Appendix IV) and that Appendix describes all the tests in detail. This was the first goggle which successfully met the severe demands of the new

tests when the velocity of the projectile in the impact test was 390 ft. per second. It was found that the goggle was successful when the front lens was 0.050 inches thick and the back one 0.080 inches thick. It was also successful when fitted with two lenses each 0.080 inches thick.

52. Single lenses made of polycarbonate material which was two millimetres thick (approximately 0.080 inches) were then substituted for the double acetate lenses in these cup type goggles. Once again the goggles were successful, even when on this occasion the velocity of projectile in the impact test was increased to 500 ft. per second.

53. Subsequent work done in connection with the problem of protection from infra-red radiation showed that a suitable glass lens could be fitted between the two plastic lenses of the double goggles when the goggle would still withstand the impact tests (see Appendix VI). Similarly, it was shown that a suitable glass lens could be mounted in front of the single polycarbonate lens when the impact value of the goggles would be unimpaired.

Visor Type Goggles

54. Visor type goggles were then fitted with lenses made from the polycarbonate material, these lenses being two millimetres thick. The goggles withstood all the tests including the impact test when the projectile velocity was 500 ft. per second. It should be noted that when these visor type goggles were worn by men who were working over molten metal, the lenses fell out of some of the early specimens owing to the distortion of the frames, so that special precautions will have to be taken to secure the lenses in certain conditions.

Face Screens

55. Finally the Sub-Committee tested face screens which had been constructed from a two millimetre thickness of the polycarbonate sheet. These screens withstood all the tests including the impact test when the velocity of the projectile was 500 ft. per second.

OPTICAL PROPERTIES

56. The goggles which are selected for the protection of men at risk from molten metal should comply with the relevant British Standard Specifications ^{6, 7, 8, 9} so far as their optical properties are concerned. For the purpose of these specifications the following ranges are used:—

- (a) Ultra-violet.—Radiation beyond the violet end of the visible spectrum, i.e. of wave lengths less than about 4,000 Angstroms.
- (b) Light.—Radiations within the visible range of the spectrum, i.e. of wave lengths approximately from 4,000–7,500 Angstroms.
- (c) Infra-red.—Radiation beyond the red end of the visible spectrum, i.e. of wave lengths greater than about 7,500 Angstroms.
- (d) Total heat.—Radiation of all wave lengths.

Light

57. When only the visible range of the spectrum is involved, goggles should meet the optical requirements⁶ of British Standard 2092: 1962.

Ultra-Violet

58. The effects of ultra-violet radiation are mentioned in British Standard 679: 1959, which remarks³ that "comparatively brief exposure to intense sources of ultra-violet radiation may induce severe irritation of the eyes and other painful symptoms so that protection is necessary in all welding operations". This is not perhaps a particular risk in the handling of molten metal except in the use of the electric arc furnace but either glass or plastic lenses can be made that will give protection wherever it is needed.

Infra-Red

59. British Standard 1729: 1952, states that "The disease known as cataract is produced by long exposure of the unprotected eyes to infra-red radiation". It adds that "No evidence could be obtained indicating incidence of eye cataract among steel melters due to furnace radiation". The Standard then specified a green glass that would give a considerable measure of protection against infra-red.

60. It is sometimes thought that glass gives protection against infra-red, but it is a matter of some importance to realise that the cobalt blue glasses so often worn against the radiations from steel furnaces do not protect against infra-red since they transmit it to a considerable extent. Protection is given by the green glasses specified in British Standard 1729: 1952, but this should be sharply differentiated from the false sense of protection that so often accompanies the use of blue glasses.

Total Heat

61. Sometimes the necessary protection is specified by placing a limit on the total amount of radiation of all wavelengths (from ultra-violet to infra-red) transmitted by the lens relative to the amount of light transmitted.

Protection against Infra-Red

62. Plastic materials do not protect against infra-red. This protection can be obtained, however, even when plastic lenses are selected because of their impact value, by using a suitable glass lens between double plastic lenses, or by putting a suitable glass lens in front of the single plastic lens. Such lenses have been tested and details of the experimental work are given in Appendix VI.

63. The introduction of glass increased the resistance to impact of the plastic lenses to the extent that besides withstanding the test at 390 ft. per second they could all be tested at 500 ft. per second. In consequence the test at the higher velocity was used on all these lenses. In no case did the projectile penetrate the lens, and in only one test was the plastic lens nearest to the eye of the wearer cracked. The glass and plastic lenses were also satisfactory against molten metal.

64. Protection against infra-red radiation can therefore be provided, when it is needed, by the use of glass and plastic lenses, and these lenses will at the same time give protection against molten metal and high impact. The glass should never be put behind the plastic because if the lens is struck by a projectile moving at some speed the glass may be driven in a shower of splinters into the eye of the wearer. If glass is used on the front of the composite lens it offers the advantage of being harder than plastic and therefore not so susceptible to scratching.

MISTING

65. Misting can be a real problem in the conditions of a foundry but plastic materials mist less than glass so that the goggles which give the best protection against molten metal are also least subject to misting. "Anti-dim" compounds may be used but one simple way of reducing misting when using goggles to protect against molten metal is to warm them before putting them on. Adequate ventilation of the lenses is essential, but we do know of one iron foundry where cupola keepers are wearing the cup type plastic goggles which the Sub-Committee has evolved and, even without anti-dimming compounds, the men say that they have no serious trouble with misting.

DURABILITY

66. Plastic materials are much softer than glass. In consequence they scratch much more easily. It is, therefore, possible to ruin a pair of plastic goggles in a few seconds by "cleaning" them with a cloth which contains pieces of grit which act as an abrasive and score the lenses. We have been told of plastic goggles which lasted only a few hours. On the other hand ordinary spectacles can be, and are, made of plastic materials, and with proper treatment they will last for years. It is a matter of common knowledge too that thousands of pairs of plastic goggles are in use in the industrial world so that the softer surface of the material is by no means an insuperable disadvantage. Our Sub-Committee put their new cup type goggles with double acetate lenses into use in one mechanised iron foundry and after more than two years of experience it has been found that the lenses last for about three weeks, when they need replacing. This life has been achieved without any special attempt to improve it and there is no doubt that if the men always cleaned the lenses under running water and avoided rubbing them with any piece of cloth that happened to be available, they would last longer. In fact one dresser in the same foundry has worn a visor type goggle for three months and would have gone on wearing it if it had not been withdrawn for examination and test. It may be considered that a pair of plastic lenses every three weeks or thereabouts is a reasonable price to pay for a standard of protection so high that, if the wearer survives an accident, he will almost certainly find his eyes undamaged.

67. Plastic face screens made of the polycarbonate material have been used in a fettling shop for six weeks in order to test their resistance to abrasion. At the end of a six-week period of continuous use they were repolished and put back into the shop, to be used for another eight weeks before being withdrawn for testing. Similar screens have also been used in an aluminium diecasting foundry to protect against the risk from molten metal.

COMFORT

68. We appreciate that comfort is an important factor in persuading people to wear goggles for long periods of time. While not having been able specifically to investigate this aspect of the matter, the Sub-Committee has produced three types of goggles in an effort to meet individual preference and to provide at least two types which can be worn over ordinary spectacles. We hope that manufacturers of goggles will persist in developing any further types that might be necessary in order to provide comfortable goggles for the people who

have to wear them. We may remark in passing that, whenever the goggles can be fitted to the wearer, they will be more comfortable; so that we suggest that founders who can do so will arrange to have the distribution of goggles supervised by a person with some knowledge of the problem, e.g. in a Medical Department.

IMPACT GOGGLES

69. Our work has produced goggles which will give protection against impact to a degree so far in excess of anything yet known that it is not of the same order of magnitude. The standards of protection against impact which have been used in the past are now so low as not to be at all comparable with the new standards which are easily and readily attainable with the plastic goggles we have developed. The use of goggles against impact in circumstances in which molten metal is not present does not concern us and is outside our terms of reference. Nevertheless, the standard of protection against impact has been so remarkably improved by the work of the Sub-Committee that we think we should be failing in our simple duty if we did not draw your attention to it.

CONCLUSIONS

70. From all this work we draw the following conclusions:

- (1) That the standard required of personal appliances for the protection of the eyes can only be defined by stating that, if the wearer of any such appliance survives an accident, his eyes should not be damaged.
- (2) That we can find no form of glass which will give this standard of protection against molten metal and high impact.
- (3) That glass is always broken by molten metal and that it offers a low standard of protection against impact.
- (4) That glass produces a secondary hazard when broken, from fragments or from splinters thrown off from the side of the lens that is adjacent to the eye of the wearer.
- (5) That wire mesh is liable to be penetrated by molten metal.
- (6) That certain plastic materials which are readily available will virtually give the standard of protection defined in Conclusion (1) above.
- (7) That as a result of the work of our Sub-Committee, cup type goggles, visor type goggles and face screens have been developed to withstand molten metal, hot solid metal, and the impact of $\frac{1}{4}$ inch steel ball bearing moving either at 390 ft. per second, or at 500 ft. per second.
- (8) That plastic or glass lenses can be made to protect against ultra-violet radiation but that plastic materials do not at present give protection against infra-red.
- (9) That the standard of protection defined in Conclusion (1) above can be associated with adequate protection against infra-red by incorporating suitable glass filters in the plastic goggles.
- (10) That internal strain in plastic material weakens it to impact but that this strain can easily be detected in examination in polarised light.

- (11) That plastic materials are softer than glass and so scratch more easily. It is important that they be cleaned carefully to avoid scratching; probably the best method is to rinse them under running water. In spite of this disadvantage, however, many thousands of plastic goggles are in use throughout industry so that the disadvantage is obviously by no means insuperable.
- (12) Much of the work of the Sub-Committee has, perforce, been empirical although considerable efforts have been made to obtain systematic series of results. We have no doubt that more work remains to be done. For example, materials should be tested to destruction and a series of impact tests using different weights and different sizes of projectiles moving at different velocities is needed to provide systematic information. Other materials should be examined and developed, and other types of goggles designed. We hope that the industry which is concerned with the manufacture of goggles will be sufficiently stimulated by our results to undertake this work.

RECOMMENDATIONS

71. In our Terms of Reference you asked us to advise you as to "the most efficient" type of personal eye protection to be worn by men at risk from molten metal. We know that the toughened and laminated glass goggles that have been used in the past will protect against light sparks and splashes. But we know too that glass is nearly always broken by molten metal and that when laminated glass is struck on the front surface and cracked, small splinters often fly from the back surface; as this is the surface adjacent to the wearer's eye, this fact does not give us much confidence in the lens. We know now that certain plastic goggles will give protection against both molten metal and the high impact which may be associated with it. Plastic goggles have withstood the impact of a $\frac{1}{2}$ inch diameter steel ball travelling at 500 ft. per second, (i.e. about 340 miles an hour). Our Sub-Committee's equipment was quite inadequate to break or penetrate this plastic even at these speeds and with twelve shots in one place. On the other hand, glass failed all the new tests that were applied. Plastic lenses do not protect against infra-red radiation, but when this protection is necessary it can be provided by incorporating a suitable glass filter which should either be fitted between plastic lenses or be backed by a plastic lens so that the glass protects against the infra-red and the plastic against impact and molten metal.

72. You will notice that we have included two impact values. This is because two different plastic materials have met the two different values but we think that either is sufficient for the general purpose of protecting foundry workers, even though the standard requiring 500 ft. per second is higher than that requiring 390 ft. per second. In effect we are suggesting a suitable range of impact values. If subsequent experience requires the higher standard this can easily be applied, but we think at present that the standard that is finally used will be the one which is obtained by the material which proves most suitable in practice; and that this may be determined on considerations other than those of impact value. In our recommendations we use the phrase "not less than 390 ft. per second" because this phrase covers the range 390 ft. per second to 500 ft. per second and because some of the goggles withstood 390 ft. per second and some withstood 500 ft. per second.

73. In view of all the evidence, and of the very great superiority of plastic materials over glass, even if it does protect against light sparks or splashes, we can no longer consider either toughened or laminated glass to be the material that gives "the most efficient" protection. Nor can we again think that goggles made of any type of glass that has yet been produced will provide "the most efficient type of personal eye protection to be worn by a foundry worker at risk from molten metal". We therefore append the following recommendations in answer to the question contained in our Terms of Reference, and we are satisfied that compliance with all these eight recommendations will give the most efficient type of personal eye protection that can at present be obtained for foundry workers at risk from molten metal.

Recommendations

- (1) That no wire mesh be used for the protection of the eyes.
- (2) That no metal, used in the construction of goggles, be exposed to impact by molten metal.
- (3) That goggles be constructed of such materials and in such a fashion that they will withstand the tests described in this Report when tested in the appliances here described, or in other appliances which may be designed to give equivalent results.
- (4) That lenses be constructed of such materials as will withstand the impact of molten metal when tested in some such appliance as was described for the purpose in this Report (see Appendix I). That notwithstanding this, a glass filter may be used to protect against infra-red radiation so long as it is (a) backed by a plastic lens which will withstand both impact by molten metal and cold impact from a $\frac{1}{4}$ inch diameter ball bearing striking the lens when mounted in the goggle, at a velocity of not less than 390 ft. per second; or (b) placed between double plastic lenses so that the triple lens so formed will withstand both the impact of molten metal and the impact of a cold $\frac{1}{4}$ inch diameter ball bearing striking the lens when it is mounted in the goggle, at a velocity of not less than 390 ft. per second.
- (5) That goggles be so constructed that the lenses when mounted in the goggles will withstand the impact of a cold $\frac{1}{4}$ inch diameter steel ball bearing striking them at a velocity of not less than 390 ft. per second.
- (6) That materials used for lenses conform to the optical requirements of the relevant British Standard.
- (7) That lenses be large enough to give both proper protection and an adequate field of vision.
- (8) That goggles be properly ventilated to avoid as far as possible the difficulties associated with misting.

ACKNOWLEDGMENTS

74. We are indebted to our Sub-Committee for the work that they have done; to Mr. Livermore of the Midland Motor Cyclinder Company Limited for much continued encouragement and assistance; to Major Reid of the Ministry of Supply, and to Dr. Holland of Triplex Glass Company Limited, for technical discussions on particular aspects of the work; to Imperial Chemical Industries

Limited, B.X. Plastics Limited, Parmalee (G.B.) Limited, Triplex Safety Glass Company Limited, British Celanese Limited, Bakelite Limited and Mine Safety Appliance Company Limited, for specimens for testing. We are under considerable obligation to Midland Motor Cylinder Company Limited for facilities for practical work, to the directors of B.S.A. (Guns) Limited, for the prototype air rifle, and to Mr. C. T. Knott of William Stephens Limited for assistance in the design and construction of goggles. Without all this assistance the work could not have been done.

(Signed) H. WOODS (*Chairman*)

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26th September, 1963

APPENDIX I

CONTENTS

	Page
First Interim Report of the Joint Advisory Committee on Foundry Goggles	20
INTRODUCTION	20
TESTS OF MATERIALS	21
INTERPRETATIONS OF TEST RESULTS	21
OTHER CONSIDERATIONS	22
RECOMMENDATIONS	23
ACKNOWLEDGMENTS	23
First Interim Report of the Sub-Committee of the Joint Advisory Committee on Foundry Goggles	25
Membership of the Sub-Committee of the Joint Advisory Committee on Foundry Goggles	25
INTRODUCTION	26
EMPIRICAL TESTS	28
CENTRIFUGAL TESTING MACHINE	28
LOW VELOCITY BALLISTIC TESTS	28
Spring Loaded Testing Machine	28
First Series of Tests	28
Second Series of Tests	29
Third Series of Tests	30
Fourth Series of Tests: Non-ferrous Metal Tests	30
Calibration of Machine	31
Fifth Series of Tests	32
Hot Solid Projectiles	32
Results	32
HIGH VELOCITY BALLISTIC TESTS	33
THE EFFECT OF HEAT	34
NEEDLE TESTS	34
Calibration	34
First Series of Tests	36
CONCLUSIONS	36
ACKNOWLEDGMENTS	36
TABLES	37

FIRST INTERIM REPORT OF THE JOINT ADVISORY COMMITTEE ON FOUNDRY GOGGLES

Sir George Barnett,

H.M. Chief Inspector of Factories

INTRODUCTION

1. In 1955 you invited representatives of the Employers' Federations, the Trade Unions, the British Standards Institution and certain Research Organisations and Universities to form a Committee to advise you on some aspects of the use of goggles in the Foundry Industry. The Committee held its first meeting on 20th October, 1955, when you gave to it the following terms of reference:

"To advise H.M. Chief Inspector of Factories as to the most efficient type of personal eye protection to be worn by a foundry worker at risk from molten metal".

2. During the course of our work we have examined an analysis of all the eye accidents that occurred in the Foundry Industry in 1954 and 1956. We have visited three foundries, we have searched the literature for work done in this country and overseas, we have held discussions with interested individuals, firms and organisations, and have initiated and carried out research on certain aspects of the problem presented to us.

3. Apart from one very comprehensive American report* we have found no published work to assist us and we decided to do our own experimental work. We set up a Sub-Committee for this purpose, consisting of Mr. G. T. Hyslop, Mr. A. W. Bushell and Mr. W. B. Lawrie and gave them powers to co-opt. This Sub-Committee has now completed a large amount of work for us and its results are presented in Appendices I and II which represent the first report of the Sub-Committee to us. The work has not yet been completed but some definite conclusions have been reached. Our terms of reference refer to "a foundry worker at risk from molten metal", but the Sub-Committee has pointed out that a molten metal splash may solidify as it passes through space so that the foundry worker may be struck by hot solid metal even though he may be properly said to be "at risk from molten metal". It has in the past been customary to test goggles by means of "cold tests", and in order to correlate their molten and hot metal test results with existing test results the Sub-Committee has done some work on cold testing. There has, therefore, been some divergence from the strict letter of our terms of reference, but only so as to ensure that any recommended form of eye protection would, in fact, protect "a foundry worker at risk from molten metal".

4. The Sub-Committee has dealt both with the strength of the materials of which lenses may be made and especially with their resistance to penetration by molten and hot metal. There has not yet been time to deal fully with many other matters which are involved in the provision of suitable eye protection and this report deals mainly with the physical resistance to penetration of certain materials

*Final Report on the American Society of Safety Engineers' Research Project—Plastic Eye Protectors.

which might be suitable for use as eye protectors. It does not deal with other aspects of the problem such as the optical properties of these materials and the correct design of goggles.

5. In April, 1956 you issued at our request a letter to certain interested organisations in which you stated our views at that date. The results of the subsequent experimental work, including exacting tests on various materials carried out by the Sub-Committee, together with certain other results obtained from different sources, have altered our views appreciably.

TESTS OF MATERIALS

6. The Sub-Committee has tested specimens of laminated glass lenses and toughened glass lenses, as well as a range of plastic materials including one type of laminated plastic lens. After they had devised and made a suitable testing machine the Sub-Committee tested the various lenses by projecting molten metal against them. In this series of tests they used varying weights of steel at 1,600°C, iron at 1,450°C, phosphor bronze at 1,150°C, gun metal at 1,150°C, aluminium at 750°C and white metal at 500°C. In all cases the plastics were, under the conditions of test, superior to either toughened or laminated glass. The Sub-Committee also used both hot and cold solid projectiles on the machine and consistently found that the plastic materials were superior. The Sub-Committee developed a second testing machine in which a needle was used to determine the resistance of the goggle lenses to penetration. Once again in all cases the plastic materials were superior. Finally the Sub-Committee did some further tests on the plastic materials in an effort to determine the ease with which they might burn if they were struck by a red hot piece of metal at such a velocity that it was embedded in the lens. In this series of tests some of the plastic materials were better than others.

Certain high speed ballistic tests have also been brought to our notice. In these tests the lenses were struck by a projectile which weighed about one gramme and which was made in the form of a cube. At the moment of impact the projectile which was fired from a shot gun was moving at velocities between 800 and 1,000 feet per second. The results of the tests indicated that a laminated plastic lens withstood the missile at speeds up to 850 feet per second but that toughened or laminated glass failed at much lower velocities.

INTERPRETATIONS OF TEST RESULTS

7. In the earlier recommendation on which you based the letter to which reference has been made, we unanimously rejected the use of wire mesh in any form other than as side pieces because we were satisfied that high velocity molten metal meeting it directly could penetrate it. Because of this weakness, wire mesh should not be used at all as eye protection against molten metal.

The Sub-Committee's work has shown that the recommendation as regards laminated and toughened glass was not well founded and that other materials give better protection against molten metal. We know now that when laminated glass is struck on the front lens and cracked, small splinters often fly off the back lens and as the back lens is the one that is adjacent to the eye of the wearer, this fact does not give us much confidence in the lens. We know too that while laminated and toughened glass will give protection against light sparks and splashes, the plastic materials tested, if of adequate thickness, will protect

against heavy splashes of molten metal. These plastics are, therefore, so superior to glass in protection against molten metal that we no longer consider either laminated or toughened glass to be the most efficient material for this purpose. The reasons for these conclusions have been fully set out by our Sub-Committee in their report which forms Appendices I and II. We know that some plastics give better results than others, that some burn and some do not, that some warp easily under the influence of heat and that many of the plastics are soft enough to be easily scratched.

OTHER CONSIDERATIONS

8. We have not investigated very closely the optical properties of the various plastics, nor have we examined in any detail the problem of providing prescription lenses or the manufacturing difficulties that might be involved in the use of plastic lenses. But notwithstanding the incomplete nature of the investigations it is felt that some specific recommendations can be made. Having discovered that some materials will afford satisfactory resistance to molten metal and other projectiles the next part of the problem was to decide what standard of protection should be aimed at, that is, complete eye enclosure or something less, and then to decide what type or types of equipment will provide this standard of protection.

Closely allied to this part of the problem is the difficulty in getting workmen to make proper use of the equipment provided. There can be no doubt that this difficulty has been due to some extent to the provision of unsuitable and unsatisfactory equipment. The frequent complaints about discomfort and misting-up are by no means unfounded.

9. In seeking a practical solution the Committee has come to the conclusion that in order to get the men to wear the equipment it might be necessary to provide a device which does not give complete eye enclosure but which will meet the requirements of regulation 8(1)(c) Iron and Steel Foundries Regulations 1953 for it does not seem that absolute enclosure is thereby necessarily required. It has been established that many men will wear a spectacle type of eye protection much more readily than goggles or other types which give complete enclosure but many of which restrict the field of view, and, due to inadequate ventilation, are very liable to become misted-up. Spectacles provide a very high degree of protection particularly when side wings are added. These side wings should be of non-perforated transparent plastic material. Examination of the reports of investigation of accidents to eyes which have occurred in foundries due to molten metal confirms that a large proportion would have been prevented if the injured person had been wearing spectacle type protection. The Sub-Committee has pointed out one serious drawback to the use of metal in conjunction with plastic materials in that molten metal tends to adhere to the solid metal and so damage the adjoining plastic material. This disadvantage can probably be overcome by coating metal frames and ear-pieces with plastic.

10. The importance of correct fitting must be stressed, and it is of even greater importance when complete eye enclosure is not provided. If the spectacle type becomes a standard which is worn by the workers then the approach to ideal protection will be enhanced by individual fitting of the spectacles. Moreover, comfort in wear (or the lack of it) has been the major cause of non-co-operation by the workers; individual fittings will do much to meet such objections.

11. In order to secure proper compliance with regulation 8(1)(c) of the Iron and Steel Regulations 1953, it is necessary that there should be the fullest co-operation of both employers and workmen; we are satisfied that such co-operation will be greatly facilitated by the adoption of our recommendations in the next paragraph.

It is therefore suggested that the necessary publicity should be given to this report in order to facilitate and expedite the practical application of our recommendations.

RECOMMENDATIONS

12. Our recommendations are briefly that:

- (i) Plastic materials as a class give the most effective protection against molten metal and within this class laminated plastic lenses are superior to any other. We, therefore, recommend that their development should be encouraged and expedited.
- (ii) The spectacle type with side wings is one practical form of eye protection likely to achieve a substantial reduction in accidents, the individual fitting of such eye protection being a necessary requirement in achieving this object.
- (iii) It is, however, intended that where goggles and eye-shields providing complete enclosure of the eyes are at present in use, such use should continue and, indeed, the use should be extended where conditions of work allow.
- (iv) There are some types of eye protection in use at the present time which do not conform to these standards, but they should not be discarded until better protection is available.
- (v) There will be interpretations (and we know of some at present) of these recommendations which because of inferior workmanship, manufacture and unsuitable materials used will not meet the high standard of durability which is necessary under the particular conditions obtaining in foundries. It is suggested, therefore, that there should be an advisory panel to give—say—a hall mark to the products which makers offer to the industry. This panel could well be chosen from members of the optical associations and the British Standards Institution and meet under the aegis of H.M. Chief Inspector of Factories.
- (vi) In paragraph 5 we referred to the letter which was circulated to the Foundry Industry, with certain recommendations based on some preliminary information. The Committee regrets any misapprehensions which may have been caused by this letter, and suggests that the earliest opportunity should be taken to correct them.

ACKNOWLEDGMENTS

13. (i) The Committee wishes to record its thanks for the help and advice it has received particularly on the question of correct fitting referred to in paragraph 10 from the British Optical Association, the Guild of British Dispensing Opticians, the Association of Wholesale Manufacturing Opticians and the Joint Committee of Ophthalmic Opticians,

and is particularly grateful for an offer of assistance from these bodies in establishing a nation-wide service which will ensure correct initial fitting and subsequent maintenance. A committee has been formed by these Associations to consider the best method of putting this into effect and its recommendations can be expected shortly.

Thanks are also due for help and advice received from Employers' Federations, Trade Unions and many individual firms, with particular thanks to the Midland Motor Cylinder Company Limited for providing the facilities for most of the tests carried out by the Sub-Committee.

- (ii) The Committee also wishes to record its great appreciation of the work of the Sub-Committee which by its thorough nature gave considerable assistance in enabling your Committee to present this Report at so early a stage.

The work of the Committee has been greatly facilitated by the able help of our Secretary, Mr. W. A. Attwood, to whom we are most grateful.

We have the honour to be, Sir,

Your obedient servants,

(Signed) R. BRAMLEY-HARKER (*Chairman*)

A. W. BUSHELL

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W. A. ATTWOOD (*Secretary*)

August, 1957

FIRST INTERIM REPORT OF THE SUB-COMMITTEE
OF
THE JOINT ADVISORY COMMITTEE ON FOUNDRY GOGGLES

Members of Sub-Committee

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Mr. G. T. Hyslop*

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* Resigned 6th March, 1957

FIRST INTERIM REPORT OF THE SUB-COMMITTEE OF THE JOINT ADVISORY COMMITTEE ON FOUNDRY GOGGLES

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INTRODUCTION

1. The protection of the eyes of foundry workers by means of goggles, spectacles or visors involves ophthalmological considerations, questions of comfort and other matters which we have not considered. We have dealt only with the strength of the materials of which lenses may be made and especially with their resistance to penetration by molten and solid metal projectiles. In most instances we have tested lenses only, as we have not yet had time to construct suitable machines for the testing of complete goggles. Neither have we been able to test every make of material in the time available. We have, however, tested toughened glass, laminated glass, Perspex (methyl methacrylate) laminated Perspex, an allyl resin, Cobex (a co-polymer which is essentially a rigid polyvinyl chloride) and Bexoid (a cellulose acetate), together with sundry other acetate specimens which were taken from goggles and visors which we found in use in the industry.
2. We considered that the physical properties of any material that might be used for eye protection should be determined if they were not already known. The only British information available appeared to be the British Standard 2092: 1954 which specified an impact test and in addition to this we examined the final report of the American Society of Safety Engineers on Plastic Eye Protectors. We decided that we needed more precise details on the behaviour of lenses under impact from molten metals and so we concentrated our efforts in the first instance on this aspect of the matter. Once this had been done we thought that the other physical properties as shown by the normal tensile test, compression test and the like could be obtained from the makers of the various materials. Even if this latter information was not available we assumed that it could be obtained readily enough.
3. In addition to the physical properties we think that chemical properties as they affect the durability of lenses in foundry conditions and optical properties such as light transmission, internal reflection, the absorption of infra-red radiation and so forth should also be examined in order to be able to select the best material for the lenses. We believe, however, that the question of resistance to penetration by molten metal is by far the most important and must be answered first. Materials which do not offer protection in this sense should not be used whatever their optical properties, because it is manifestly useless to discuss the effect of infra-red radiation on the eyes if they cannot first be protected from physical destruction by molten metal which has penetrated the goggle lens. As a first step, therefore, we have confined ourselves entirely to the discovery of materials which would not be penetrated by molten metal and this first report deals only with this single aspect of the matter.

4. We found little enough published work on the subject and we did not think that the information we received indicated suitable methods of testing. The first necessity therefore was to devise a testing machine.

Our preliminary discussions centred around the severity of the test. We think it impossible to define "average risk". Very occasionally, moulds explode after being cast, when the total weight of metal in the mould may be thrown violently into the air. This may represent many tons of metal, but on the other hand very small splashes occur frequently, and the weight of metal in these splashes may be so small as to require a chemical balance to determine it. We cannot therefore suggest an average weight for splashes of molten metal, nor can we suggest an average velocity for splashes moving through the air. We think it might be possible to determine specific velocities in particular cases by means of a cinematograph camera, but we decided that this was not sufficiently important to occupy our time in the early stages of the work.

Quite apart from metal splashes, sparks constitute a danger. Sparks may consist of metal which is in process of oxidation as it flies through the air and at the end of its trajectory a spark may contain more oxide than metal. We thought that this matter of chemical composition might have some influence on the material that should be used for goggles, and later work has confirmed this view. The diversity of metals that are melted and the diversity of casting techniques emphasised the impossibility of defining "average risk".

One further difficulty presented itself. Even if a splash of metal leaves its point of origin in the molten state, it is changing temperature continuously as it passes through the atmosphere. Normally it will be cooling but if the oxidation process is exothermic it will generate heat and the temperature will rise. Goggles may therefore be struck either by molten or by hot solid metal.

In view of all these considerations, we agreed that we should not try to devise tests that purported to simulate any such hypothetical quantity as "average risk".

5. We can only define the degree of protection that is required of goggles by stating that if a man survives an accident then his goggles should have been good enough to preserve his eyes. This is obviously an ideal which may or may not be possible. We concluded, however, that the only proper way to test was to test to destruction and this is what we have tried to do. We have not in fact succeeded in penetrating most of the plastic lenses we have tested. Indeed, we have not yet succeeded in even marking some of them, but we still think that tests should be devised, and carried out, by means of which all the possible materials can be penetrated so that we can arrange them in order of merit and also know by how much the best material exceeds the worst in its resistance to penetration. This would indicate something like an empirical factor of safety in known conditions.

We decided therefore that the test machine should be capable of penetrating all the materials tested, and although we have not yet succeeded in obtaining so severe a test we still think that this should be done. We also decided that the machine should be so designed that it could be calibrated. We appreciated that accurate results might not be obtained easily, but we thought that reasonably good approximations of the energy that lenses would absorb without being penetrated would be better than purely empirical results.

EMPIRICAL TESTS

6. A few practical tests were done in the early stages of the work on a centrifugal casting machine in which phosphor bronze was being cast at about $1,150^{\circ}\text{C}$. The mould was rotating about a horizontal axis and it was slightly over-filled with the metal so that there was a definite splash at the front opening. Plastic visors and goggles were mounted on a white card and held in the splash in close proximity to the rotating mould. Some of these plastic materials were penetrated by the flying particles but it was quite impossible to calculate the momentum of these particles, or to know whether they were fluid or solid at the moment of penetration. Later work implied that the particles which penetrated the plastics were in the solid state, but this has not yet been proved and we think that solid penetration tests are quite essential to supplement the molten metal tests.

CENTRIFUGAL TESTING MACHINE

7. A centrifugal testing machine was then constructed in which the molten metal dropped from a small crucible on to a rotating table. The specimens to be tested were mounted in a circle around the table so that the molten metal thrown from the table impinged on them. A few tests were carried out with this machine using different non-ferrous metals and in no case was a plastic material penetrated by the metal. It was noticed however that some metals adhered to the plastic specimens and some did not. It appeared therefore that different metals reacted differently to certain plastics. The machine was convenient enough in operation but it was discarded because there was no means of knowing whether the metal was solid or fluid at the point of impact with the specimen, and also because it was almost impossible to calculate the amount of energy in the flying particle when it struck the specimen.

LOW VELOCITY BALLISTIC TESTS

Spring Loaded Testing Machine

8. A new machine (see Figures 5, 6, 7 and 8) was constructed in which a spring loaded piston was fitted with an ejector head. This head was dished to a depth of half an inch to accommodate a solid or a fluid projectile. A fixed stop platform was mounted above the head and provided with a central opening large enough to allow the projectile to pass through. The specimen itself was mounted above this opening. In use, the spring is compressed and the liquid or solid projectile is placed in the dish in the ejector head. On releasing a foot catch the spring drives the ejector head vertically upwards until it strikes the stop platform. This stops the head but the projectile is thrown through the central opening in the stop platform to strike the specimen mounted above it. A sheet metal guard is placed over the specimen to collect the molten metal and any fragments that might fly from the broken specimen.

First Series of Tests

9. The first series of tests was made largely to assess the merits of the machine itself. The maximum spring tension was used and the stop platform was fixed at $22\frac{1}{2}$ " above the base. Each specimen was mounted at one of three different distances above the stop platform.

10. Eight tests were made using glass lenses. It was found that small ball-bearing projectiles did not damage either toughened or laminated glass. The size of the projectile was therefore increased until the specimens could be broken by means of a section of mild steel weighing $212\frac{1}{2}$ grammes. The laminated glass lenses, both coloured and plain, were cracked on both sides when mounted in each location stage 1, 2 and 3 and the toughened glass specimen was completely shattered in location stage 1. Only one toughened glass specimen was used as this was the only one that was available at the time. These conclusions lead to a decision to extend the thread on the stop platform control rods, so that the platform itself could be lowered to reduce the travel of the projectile ejector head before it made contact with the underside of the stop platform.

11. Molten metal tests were then made with the modified machine and in order to make first comparisons the conditions were similar to those used in the first eight tests apart from the modification of the machine itself. The specimens were mounted in the three location stages in turn and the maximum spring tension was applied, the stop platform remaining at $22\frac{1}{2}$ " above the base.

12. Ten specimens were tested with molten iron at $1,400^{\circ}\text{C} \pm 20^{\circ}\text{C}$ with the somewhat surprising result that laminated coloured glass and toughened glass were completely disintegrated in specimen location stage 3 by a charge of about 109 grammes of iron. In view of these results the stop platform was raised to 24" above the base. The last specimens continued to be completely shattered in spite of efforts to reduce the charge of molten metal.

13. The first series of tests therefore indicated that certain plastic specimens would withstand reduced charges of metal, but that both laminated and toughened glass specimens were incapable of withstanding the impact of these charges without cracking badly or shattering completely. It was clear, however, that the machine itself required certain modifications before stable results could be obtained, and so this was done as the next stage in the work.

Second Series of Tests

14. After the first series of tests were completed a second ejector head was made which held a charge of approximately 95 grammes of molten iron and a fourth specimen location stage was built on top of the three already provided.

15. In the second series, ten tests were made using molten iron at $1,400^{\circ}\text{C} \pm 20^{\circ}\text{C}$ as the projectile. This second series of tests confirmed the first series. The plastics withstood the impact of the molten metal, the toughened glass was completely shattered and the laminated glass was very severely cracked and in some cases penetrated and shattered. Both glasses were badly cracked in the laminated lenses and it was noticed that the top glass of the lens, that is the one that would be nearest to a man's eye when the lens was in use, splintered besides cracking. Close examination of this top lens showed that splinters of glass had broken away from the lens. This phenomenon was seen in many later tests and it undermined our confidence in the suitability of laminated glass lenses.

16. A further weakness was evident in the design of the test machine during this second series of tests. It was found that molten metal was being forced round the specimen so that it passed between the edge of the specimen and its retaining ring. This metal then fell back on to the top of the specimen and, in

the case of some plastic specimens, was sufficient to ignite them after they had withstood the initial impact. We decided therefore that a new type of ring should be designed to hold the specimen.

17. At this stage of the work it appeared that:

- (a) Plastic materials appear to provide infinitely better resistance to molten metal than either toughened glass or laminated glass.
- (b) Toughened glass appeared to be entirely unsuitable as it shattered in every test.
- (c) Laminated glass appeared to be unsuitable as it was very badly cracked by every test and splinters of glass were thrown off the surface which would be adjacent to the eye of the wearer if the specimen had been in normal use.
- (d) Plastic specimens did not appear to be wetted by the molten metal, and this might offer a reason for their superior behaviour.
- (e) Plastics might react differently to different metals and so tests with non-ferrous metals as the projectile were considered to be essential.

Third Series of Tests

18. The holding ring for the specimen was modified and three ejector heads were made, arranged to contain charges of approximately 30, 95 and 145 grammes of molten iron respectively. It was then decided to carry out a series of tests using toughened glass specimens, laminated glass specimens and plastic specimens, each material being tested in identical conditions.

Molten iron at $1,400^{\circ}\text{C} \pm 20^{\circ}\text{C}$ was used as the projectile throughout this series of tests, the maximum spring tension was used, the stop platform was positioned at 24" above the base and all the specimens were mounted in the new holding ring.

19. Once again the plastic materials withstood every test and, even under the maximum conditions, no single plastic specimen was penetrated by the metal. The toughened glass specimens failed every test, being completely shattered. The laminated glass specimens also failed every test. Both glasses of each laminated lens were badly cracked in every test and in some of the tests splinters had left the top glass of the lens. The molten metal adhered to all the glass lenses, but did not adhere to any of the plastics at the point of impact. Some of the plastic lenses were removed from the machine with molten metal adhering at the circumference and it was thought that this might have been due to the fact that the molten metal adhered primarily, not to the plastic specimens, but to the cold steel holding ring. By this time we had sufficient confidence in the plastics to operate the machine without the sheet metal guard which had been provided to collect the molten metal after it had penetrated the specimen. In consequence we were able to watch some of the plastics. Fairly quick observation immediately after firing the projectile showed the molten metal falling from the face of the plastic specimen and this confirmed our original view that the metal did not adhere to the plastic but only to the holding ring if it touched it.

Fourth Series of Tests: Non-ferrous Metal Tests

20. We then decided that the machine should be removed to a non-ferrous foundry, where a series of plastic and glass specimens could be tested with a range of metals. Tables I to VII give the results of these tests.

Plastic specimens were tested in thicknesses varying from 30 to 60 thousandths of an inch. 150 grammes of white metal at a temperature of $500^{\circ}\text{C} \pm 20^{\circ}\text{C}$ failed to penetrate any of the plastic specimens. There was some slight adhesion of the molten metal to the surface of the plastic lens. The white metal did not penetrate the laminated glass lens, but a large proportion of the molten projectile adhered to the glass which was badly cracked. 40 grammes of pure aluminium at $750^{\circ}\text{C} \pm 20^{\circ}\text{C}$ failed to penetrate any of the plastic specimens and the metal did not adhere to the face of the specimens. The aluminium did not penetrate the laminated glass but it adhered to the surface and cracked the lens badly. The toughened glass was completely disintegrated by the aluminium, large globules of metal penetrating the glass and adhering to the protective canister which had been placed over it. 143 grammes of phosphor bronze at $1,150^{\circ}\text{C} \pm 20^{\circ}\text{C}$ failed to penetrate any of the plastic specimens and the metal did not adhere to the plastic. 143 grammes of Admiralty gun metal at a temperature of $1,150^{\circ}\text{C} \pm 20^{\circ}\text{C}$ failed to penetrate the plastic specimens, nor did it adhere to their surfaces. The gun metal did not penetrate the laminated glass specimen but both surfaces were badly cracked and a large amount of the gun metal adhered to the impact surface of the laminated glass. Some very small splinters broke away from the top surface of this laminated specimen. When applied to the toughened glass specimen the Admiralty gun metal completely shattered the specimen. The molten metal penetrated the specimen and in this test plasticine had been mounted $\frac{1}{4}$ " above the top surface of the specimen. After the test, glass splinters were collected in this plasticine. Finally 135 grammes of stainless steel, at a temperature of $1,600^{\circ}\text{C} \pm 20^{\circ}\text{C}$ failed to penetrate the plastic specimens. After the test the specimens were found to be somewhat darkened and there was an overall clouding effect.

21. At this stage of the work observations indicated that it was possible to shatter toughened glass without projectiles simply by means of the shock transmitted through the machine when the spring was released. This observation did not appear to be a particularly good recommendation for toughened glass, but we decided that the machine must be modified and the holding ring in which the specimens are held is now mounted independently of the main machine so that the vibrations from the release of the spring and the impact of the ejector head against the stop platform cannot be transmitted to the specimen. At the same time we decided that the velocity and the momentum available in the machine should be calibrated in order that comparisons could be made, not only between materials in use in the machine but also with other methods of testing.

Calibration of Machine

22. Tables VIII to XI show the method used and the results obtained from the calibration of the machine when using solid steel ballbearings as projectiles. Tables XIV to XVI indicate the calibration done on molten iron as projectile.

23. By way of comparison the formula $V = \sqrt{2gh}$ was applied to the British Standard Test when the velocity at the point of impact with the lens was found to be approximately 16.4 feet per second. Using $\frac{7}{8}$ " diameter steel ball this would correspond to a momentum of about 738 grammes/ft./sec. These figures are included in this report to indicate the comparative severity of the present testing machine and the British Standard Test.

Fifth Series of Tests

24. Before commencing molten metal tests with the modified machine a series of tests were done on toughened glass and laminated glass specimens using steel ballbearings as projectiles. The results of these tests are given in Tables XII and XIII. It should be noted in comparing these tests with the British Standard Test that the specimen was held rigidly in the machine, whilst in the British Standard Test some of the impact is taken by the resilience of the mounting.

25. A series of tests was then done using a variety of plastic specimens, toughened glass and laminated glass with molten cast iron at $1,400^{\circ}\text{C} \pm 20^{\circ}\text{C}$ as the projectile. In all cases the maximum spring tension was maintained and the stop platform was fixed at 24" above the base of the machine. The general result was that all the glass specimens were completely shattered and that all the plastic specimens which were greater than 10 thousandths of an inch in thickness resisted penetration by the molten metal. The results are given in detail in Tables XVII to XXIII. Further work still remains to be done to arrange the various plastic materials in order of merit but the distinction between plastic and glass seems to be clear enough.

Hot Solid Projectiles

26. In order to complete the work on this machine, we then decided to use hot solid projectiles. 1" diameter solid steel ballbearings were heated to 900°C and used as projectiles. The maximum spring tension was applied, the height of the stop platform remained at 24" above the base of the machine and the specimens were located at a distance of 3" above the stop platform. The hot projectiles shattered the glass lenses just as readily as did the cold projectiles but the only effect that the hot projectiles had on the plastic lenses was to leave a slight burn mark at the point of impact. Table XXIV gives the detailed results of this series of experiments.

Results

27. The low velocity ballistic tests conducted on the spring loaded piston operated machine indicated the following conclusions:

- (a) Toughened glass appears to be quite useless as protection against molten metal.
- (b) Laminated glass is always broken by molten metal and in some cases splinters fly off from the surface of the laminated glass that would be adjacent to the wearer's eyes. It could not be said laminated glass is useless but those of us who have seen the experimental work would not be comfortable again in using the material.
- (c) Plastics appear to be greatly superior in resisting penetration by molten metal, and in fact it would be generally true to say that plastics cannot be penetrated by the machine available if they exceed 10 thousandths of an inch in thickness.
- (d) Molten metal does not appear to wet plastic surfaces but it does wet metal surfaces or glass surfaces and adheres to them. It would appear therefore that plastic lenses should not be mounted in metal rims because molten splashes will adhere to the rim and may then set fire to the plastic.
- (e) Plastic lenses were greatly superior to either toughened or laminated glass in withstanding the impact of either cold or hot solid projectiles.

HIGH VELOCITY BALLISTIC TESTS

28. When we had satisfied ourselves that the low velocity ballistic testing was giving reliable results we turned our attention to higher velocity tests because although we had decided not to attempt to define "average velocity" we knew of particular instances in which high velocity particles might be projected across a foundry. For instance cut-off wheels may work at peripheral speeds of 20,000 feet per minute. When one of these wheels breaks fragments are projected into space with an initial velocity equal to the wheel velocity, so that goggles might be struck at speeds in excess of 200 miles an hour. As we have already remarked we do not know the maximum velocity attained by metal splashes originating from explosions, nor have we made any attempt to determine it. On the other hand high velocity tests are obviously essential in view of the fact that certain flying particles are known to exceed 200 miles per hour.

29. We were informed of a research project which had been done by the Ministry of Supply and we were fortunate in having the opportunity of discussing the work with Major Reid who was responsible for it and who has given us the information contained in Appendix II.

When we thought of high velocity ballistic tests we contemplated using velocities not less than 350 feet per second. The first reason for this was that we were seeking a material that would offer protection at this velocity in view of certain known risks and the second reason was the fact that if such a material were available, still higher test velocities would be needed to test it to destruction. We hold this view because we believe that performances can never be guaranteed unless ultimate strengths and in consequence factors of safety are known. Major Reid tested at velocities up to 1,000 feet per second and although an armament manufacturer might not call this a high velocity, it is high enough for our purpose at present.

30. The high velocity tests were done on toughened glass, laminated glass, Perspex and laminated Perspex using a cold steel cube as projectile. The following four very interesting results emerged as far as we were concerned:

- (a) The tests showed that plastics were superior to glass against high velocity cold projectiles. This agreed with our own results at low velocity when using both cold and hot projectiles.
- (b) The tests showed that splinters flew off the back lens of laminated specimens, even if these were not completely shattered. This confirmed our own results at much lower velocities.
- (c) The tests indicated that plastic lenses could be made to withstand impact velocities up to 850 feet per second. This meant that the kind of protection we were seeking was in fact possible.
- (d) The tests indicated that only laminated plastic lenses would give maximum protection which appeared to depend on the soft interlayer.

THE EFFECT OF HEAT

31. Although the specimens were neither penetrated nor broken, the projectile embedded itself in the lens in those high velocity tests which resisted the impact. The tests were done cold, but we wondered whether or not the laminated Perspex would take fire if the projectile had been red hot when it embedded itself in the lens. Owing to the urgency of the work we did not attempt to repeat the tests with hot projectiles but we assumed that the effects of the impact and heat could be separated. Using the various plastic materials that had already been tested we made a cavity in suitable specimens of each so that a $\frac{1}{2}$ " diameter steel ballbearing could be laid in it when the specimen was horizontal. Essentially the cavity was hemispherical and a $\frac{1}{2}$ " diameter at the surface of the specimen, so that the ball was half in and half out when it had been inserted. The ballbearings were heated to 900°C before being placed in the cavity in a position similar to that which a cold missile would have reached if it had been projected in a high velocity test.

32. The results are given in detail in Table XXV and XXVI. It should be remembered that in practice the goggle lenses would probably be vertical when the hot missile was embedded in them, whilst in the empirical test just described, they were horizontal with the hot metal lying on the top. The tests were therefore probably more severe than the ordinary circumstances of an accident. Nevertheless, none of the specimens burned fiercely enough to reject them out of hand, although some burned with a small flame, some charred and some melted. The hot ball penetrated some of the specimens and the time of penetration varied with the thickness of the material and with its chemical composition. Once again the laminated Perspex lens gave the best results, the ball being allowed to cool to room temperature on the lens. During this time the lens did not take fire and the ball failed to penetrate it, being stopped, so far as could be seen, by the soft interlayer.

We have not yet reached any final conclusions on this aspect of the matter but it is obvious that some lenses withstand hot metal fragments much better than others.

NEEDLE TESTS

33. Before concluding the first phase of our work we thought we ought to test the resistance of the specimens to impact when using a needle as the projectile. For this purpose we designed and constructed the spring operated machine which is illustrated in Figures 9 and 10.

Calibration

34. The machine was calibrated in order to be able to compare the energy levels of the moving needle with the other tests. The calibration is not scientifically accurate as certain assumptions were made in the calculations, but we think it sufficiently close for practical purposes. The spring compression was determined against a range of loads and the results are given in Table XXVII. From this Table graph I (see Figure 11) was drawn and then used to calculate the average force as follows.

Where L = location in inches:

$$\text{Average Force} = \frac{\text{Area under curve}}{\text{location}}$$

$$= \frac{\text{Area of rectangle} + \text{Area of triangle}}{\text{location}}$$

$$= \frac{(2.5 \times L) + \frac{(2.5 + 2L - 2.5) L}{2}}{L}$$

$$= \frac{2.5L + \frac{2L^2}{2}}{L}$$

$$= \frac{5L + 2L^2}{2L}$$

$$= \frac{2L(2.5 + L)}{2L}$$

$$= 2.5 + L$$

But work done on moving parts = Force $\times$ distance

$$\text{i.e.} = (2.5 + L) L \text{ inch lbs.}$$

$$= \frac{2.5L + L^2}{12} \text{ ft. lbs.}$$

Weight of moving parts = 10 ozs. = 0.625 lbs.

Weight of spring = 0.5 ozs.

As the spring weighs only 5% of the weight of the moving parts we disregarded the energy used to accelerate the spring coils and assumed that all the energy re-appeared as the Kinetic energy of the moving parts. This Kinetic energy is given by:

$$\text{KE} = \frac{W V^2}{2g} \quad \text{where } W = \text{weight in lbs.}$$

$$V = \text{velocity in ft./sec.}$$

$$\text{i.e. } V^2 = \frac{2g \cdot \text{KE}}{W}$$

But the Kinetic energy in this expression equals the work done on the moving parts (above).

Therefore:

$$\begin{aligned} V^2 &= \frac{64.4(2.5L + L^2)}{12 \times .625} \\ &= 8.58(2.5L + L^2) \\ &= 21.45L + 8.58L^2. \end{aligned}$$

From this formula the velocity was calculated at varying locations (L) and Table XXVIII gives the results which were used to draw Graph II (see Figure 12).

The slope of this curve is $\frac{9.3}{3}$ and the graph crossed the vertical axis at 2.3.

The velocity for any given location may therefore be obtained from the following equation:

$$V = 3.1L + 2.3 \text{ where } V = \text{velocity in ft./sec.}$$

$$L = \text{location in inches.}$$

First Series of Tests

35. The results of the first series of tests are given in detail in Tables XXIX to XXXV. This work has not yet been completed, but it is evident that once again the plastic lenses are superior to either toughened or laminated glass. It appears also that the various plastics respond differently to the tests but it has not been possible in the time available to determine the precise order of merit of the different kinds and types of plastic lenses.

CONCLUSIONS

36. The work has not yet been completed but sufficient has been done to lead us to certain definite conclusions.

- (a) Toughened glass should not be used as protection against molten metal nor should it be used to protect against flying particles in foundries.
- (b) Laminated glass is always broken by the molten metal and often broken by flying particles. In some cases splinters fly off from the surface of the laminated glass that would be adjacent to the wearers' eyes. It could not be said that laminated glass is useless but those of us who have seen the experimental work would not be comfortable again in using this material. We hold the view therefore that laminated glass should not be used in foundries.
- (c) Plastics are greatly superior to glass in resisting penetration by molten metal. Much more work needs to be done in order to determine the suitability of the various plastics for use as goggles, but there can be no doubt that suitably designed plastic goggles are infinitely better than glass goggles in resisting penetration either by molten metal or by flying fragments.
- (d) The tests available show that a laminated plastic goggle was by far the best so far as physical protection is concerned. Many more aspects of the matter will have to be considered and much more work will have to be done but the experimental work to date indicates quite clearly that the laminated plastic goggle is the one that provides the maximum degree of safety.
- (e) Molten metal does not appear to wet plastic surfaces but it does wet metal surfaces and glass surfaces and adheres to them. It appears at this stage, therefore, that plastic lenses should not be mounted in metal rims because molten splashes will adhere to the rim and may then set fire to the plastic. This aspect of the matter clearly needs further consideration and probably further experimental work.

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(Signed) A. W. BUSHELL
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TABLE I

"Cobex" 50 mm. diameter specimens

Projectile: White Metal 45% tin, 1% copper, 16% antimony, 38% lead.

Temperature: $500^{\circ}\text{C} \pm 20^{\circ}\text{C}$.

Maximum Spring Tension. Height of Stop Platform: 24".

Specimen Location: 3" above Stop Platform.

Weight of Molten Metal: 150 grams.

Thickness of Specimen Thousands/Inch	Results
30	No penetration. Slight sticking at edges where molten metal in contact with holding ring. Few globules adhered. Slight clouding.
40	No penetration. Fair amount of metal adhered to specimen (molten metal passed edges of specimen due to poor fit of specimen in ring). Slight clouding.
50	No penetration. Small globules of metal adhering loosely to surface of specimen. Slight clouding.
60	No penetration. Surface covered with fine globules which had adhered very loosely (removed by touching lightly with finger). Slight clouding.

TABLE II

"Cobex" 50 mm. diameter specimens

Projectile: Pure Aluminium.

Temperature: $750^{\circ}\text{C} \pm 20^{\circ}\text{C}$.

Maximum Spring Tension. Height of Stop Platform: 24".

Specimen Location: 3" above Stop Platform.

Weight of Molten Metal: 39 grams.

Thickness of Specimen Thousands/Inch	Results
30	No penetration. Overall darkening of specimen.
40	No penetration. Centre of specimen darkened. No adhesion of molten metal.
50	No penetration. No adhesion of molten metal. Overall darkening.
60	No penetration. Overall darkening.

TABLE III

"Cobex" 50 mm. diameter specimens

Projectile: Phosphor-Bronze 89.5% copper, 10% tin, 0.5% zinc.

Temperature: $1,150^{\circ}\text{C} \pm 20^{\circ}\text{C}$.

Maximum Spring Tension. Height of Stop Platform: 24".

Specimen Location: 3" above Stop Platform.

Weight of Molten Metal: 143 grams.

Thickness of Specimen Thousands/Inch	Results
30	No penetration. Specimen darkened.
40	No penetration. No adhesion of molten metal to specimen. Overall darkening.
50	No penetration. No adhesion of molten metal to specimen. Overall darkening.
60	No penetration. Slight darkening of specimen.

TABLE IV

"Cobex" 50 mm. diameter specimens

Projectile: Admiralty Gun metal 88% copper, 10% tin, 2% zinc.

Temperature: $1,150^{\circ}\text{C} \pm 20^{\circ}\text{C}$.

Maximum Spring Tension. Height of Stop Platform: 24".

Specimen Location: 3" above Stop Platform.

Weight of Molten Metal: 143 grams.

Thickness of Specimen Thousands/Inch	Results
30	No penetration. Specimen melted at edges and somewhat darkened probably owing to delay in removing it after test.
40	No penetration. No adhesion of molten metal to specimen. Overall darkening.
50	No penetration. No adhesion of molten metal to specimen. Overall darkening.
60	No penetration. Slight burning at edge of specimen as metal adhered to holding ring. Overall darkening.

TABLE V

"Cobex" 50 mm. diameter specimens

Projectile: Stainless Steel 18% chromium, 8% nickel.

Temperature: $1,600^{\circ}\text{C} \pm 20^{\circ}\text{C}$.

Maximum Spring Tension. Height of Stop Platform: 24".

Specimen Location: 3" above Stop Platform.

Weight of Molten Metal: 135 grams.

Thickness of Specimen Thousands/Inch	Results
30	No penetration. Specimen burned and blistered whilst being removed after test. Some molten steel adhered to holding ring and burnt specimen edges.
60	No penetration. Darkening of specimen. Overall clouding effect.

TABLE VI

Laminated Glass

Maximum Spring Tension. Height of Stop Platform: 24".

Specimen Location: 3" above Stop Platform.

Projectile	Weight in grams	Temperature $^{\circ}\text{C}$	Results
White Metal	150	$500^{\circ}\text{C} \pm 20^{\circ}\text{C}$	No penetration. Glass cracked and large proportion of metal adhered to glass.
Pure Aluminium	40	$750^{\circ}\text{C} \pm 20^{\circ}\text{C}$	No penetration. Surface cracked. Metal adhered to glass.
Admiralty Gun metal	143	$1,150^{\circ}\text{C} \pm 20^{\circ}\text{C}$	No penetration. Both glass surfaces cracked. Some very small splinters broke away from surface that had not been struck. Large piece of gun metal adhered to impact surface of specimen.

TABLE VII
Toughened Glass

Maximum Spring Tension. Height of Stop Platform: 24".
Specimen Location: 3" above Stop Platform.

Projectile	Weight in grams	Temperature °C	Results
Pure Aluminium	40	750°C ± 20°C	Specimen completely disintegrated. Large globule of metal penetrated glass into protective canister behind. Some glass particles dropped back into molten metal after test.
Admiralty Gun metal	139	1,150°C ± 20°C	Overall shattering and splintering. Glass fell into molten metal after test. Some glass splinters were collected in plasticine mounted $\frac{1}{2}$ " behind the lens. Metal also penetrated lens.

TABLE VIII
Table of Solid Steel Ball Projectiles used in the Test Machine

No.	Size in inches	Actual Weight in grams	Weight used for calculation
1	$\frac{1}{16}$	1.043	1
2	$\frac{1}{8}$	2.030	2
3	$\frac{3}{16}$	3.517	3
4	$\frac{1}{4}$	7.930	8
5	$\frac{5}{16}$	28.119	28
6	$\frac{3}{8}$	44.83	45
7	$\frac{7}{16}$	54.596	55
8	1	66.706	67
9	1 $\frac{1}{16}$	79.99	80

TABLE IX
Solid Steel Balls

Table of Projected Heights in Test Machine

These heights are each the mean of three throws with each ball.
Maximum spring tension was used in each case.
The saddle stop platform was set at 24 inches.

No.	Size in inches	Height in inches
1	$\frac{1}{8}$	20
2	$\frac{1}{16}$	20
3	$\frac{1}{8}$	20
4	$\frac{1}{8}$	20
5	$\frac{1}{8}$	20½
6	$\frac{1}{8}$	20½
7	$\frac{1}{8}$	20½
8	1	20½
9	1 ½	20½

TABLE X

Test Machine Velocity using Steel Ball Projectiles

For the purpose of determining the velocity and momentum to which specimens were being subjected in the machine, simple calculations have been used which ignored those elements and conditions which would normally need to be taken into account.

$$\text{Velocity} = \sqrt{2g (\text{height of projectile})}$$

The velocity at a *given height* above the datum is obtained by using the above formula and subtracting the *given height* from the height of projection.

Size of Steel Ball in inches	Weight of Steel Ball in grams	Height of Projection in inches	Table of Velocity—feet/second				
			3"	4"	5"	6"	9"
$\frac{1}{8}$	1	20	9.5516	9.2663	8.9723	8.6659	7.6833
$\frac{1}{16}$	2	20					
$\frac{1}{8}$	3	20					
$\frac{1}{8}$	8	20	9.6908	9.41	9.1205	8.8215	7.8560
$\frac{1}{8}$	28	20½					
$\frac{1}{8}$	45	20½					
$\frac{1}{8}$	55	20½					
1	67	20½					
1 ½	80	20½					

TABLE XI

Test Machine Momentum

(Using Steel Ball Projectiles. Compiled from the Velocity Table)

Size of Steel Ball in inches	Weight of Steel Ball in grams	Table of Momentum—grams/feet/seconds				
		3"	4"	5"	6"	9"
$\frac{1}{8}$	1	9.5516	9.2663	8.9723	8.6659	7.6833
$\frac{1}{16}$	2	19.1032	18.5326	17.9446	17.3318	15.3666
$\frac{1}{32}$	3	28.6548	27.7989	26.9169	25.9977	23.0499
$\frac{1}{64}$	8	76.4128	74.1304	71.7784	69.3277	61.4664
$\frac{1}{128}$	28	267.4448	259.4564	251.2244	242.6452	215.1324
$\frac{1}{256}$	45	429.8220	416.9835	403.7535	389.9655	345.7485
$\frac{1}{512}$	55	525.3380	509.6465	493.4765	476.6245	422.5815
1	67	639.9572	620.8421	601.1441	580.6153	514.7811
1 $\frac{1}{16}$	80	764.1280	741.3040	717.7840	693.2720	614.6640

TABLE XII

Toughened Glass Tests

Solid Projectiles

Maximum Spring Tension

Height of Stop Platform 24"

Size of Steel Ball in inches	Height of Specimen above Stop Platform (inches)				
	3"	4"	5"	6"	9"
$\frac{1}{8}$	No effect	No effect	No effect	No effect	No effect
$\frac{1}{16}$	No effect	No effect	No effect	No effect	No effect
$\frac{1}{32}$	No effect	No effect	No effect	No effect	No effect
$\frac{1}{64}$	No effect	No effect	No effect	No effect	No effect
$\frac{1}{128}$	No effect	No effect	No effect	No effect	No effect
$\frac{1}{256}$	No effect	No effect	No effect	No effect	No effect
1	No effect V	No effect	No effect	No effect	No effect
	No effect W	No effect X	No effect Z	Completely shattered	No effect Y
1 $\frac{1}{16}$	Completely shattered	Completely shattered	Completely shattered	Completely shattered	No effect

V—In one instance a specimen withstood this blow, but completely disintegrated about one minute later.

W—Six repeated shots at this stage gave three glasses with no effect and three completely shattered.

X—One glass shattered at the third blow. Another glass withstood four blows, and a third glass was shattered by the second blow.

Y—One glass shattered at first blow. Five successive repeat blows failed to shatter another glass.

Z—One glass was shattered by the third blow.

TABLE XIII
Laminated Glass Tests

Solid Projectile
Maximum Spring Tension
Height of Stop Platform 24"

Size of Steel Ball in inches	Height of Specimen above Stop Platform (inches)				
	3"	4"	5"	6"	9"
$\frac{1}{8}$	No effect	No effect	No effect	No effect	No effect
$\frac{1}{16}$	No effect	No effect	No effect	No effect	No effect
$\frac{1}{32}$	No effect	No effect	No effect	No effect	No effect
$\frac{1}{64}$	No effect	No effect	No effect	No effect	No effect
$\frac{1}{128}$	No effect V	No effect X	No effect V	No effect V	No effect Y
$\frac{1}{256}$	No effect V	No effect V	No effect V	No effect V	No effect V
$\frac{1}{512}$	No effect V	No effect V	No effect V	No effect V	No effect V
1	No effect V	No effect V	No effect V	No effect V	No effect Y
1 $\frac{1}{16}$	No effect W	No effect V	No effect V	No effect V	No effect V

V—Both glasses cracked. Minute splinters came off the top glass (i.e. the glass which would be adjacent to the eye in a pair of goggles).

W—Both glasses cracked. Small splinters came off both glasses.

X—Both glasses cracked. No splinters off either glass.

Y—The impacted glass remained intact. The top glass was cracked and minute splinters came off.

Z—The impacted glass remained intact. The top glass was cracked but there were no splinters.

TABLE XIV
Test Machine
Cast Iron Ejector Heads
Weights and Projected Heights of
Solidified Charges

Maximum Spring Tension
Height of Stop Platform 24"

Size	Actual Weight of Trial Charge (grams)	Estimated average charge weight used for Calculations (grams)	Height of Projection in machine (inches)
Small Ejector Head	33.4911	35	18
Medium Ejector Head	90.7042	95	18
Large Ejector Head	141.9522	145	21

TABLE XV
Test Machine Velocity

Solidified Cast Iron Charges used as Projectiles
Maximum Spring Tension
Height of Stop Platform: 24"

Size of Head	Weight of Average Charge (grams)	Height of Projection (inches)	Velocities (feet/second)				
			3"	4"	5"	6"	9"
Small	35	18	8.9723	8.6679	8.3526	8.0249	6.9499
Medium	95	18					
Large	145	21	9.8286	9.5516	9.2663	8.9723	8.0249

TABLE XVI
*Test Machine Momentum
Compiled from Velocity Table*

Solidified Cast Iron Charges used as Projectiles
Maximum Spring Tension
Height of Stop Platform: 24"

Head Size	Weight of Average Charge (grams)	Table of Momentum (grams/feet/second)				
		3"	4"	5"	6"	9"
Small	35	314.0305	303.3765	292.3410	280.8715	243.2465
Medium	95	852.3685	823.4505	793.4970	762.3655	660.2405
Large	145	1425.1470	1384.9820	1343.6135	1300.9835	1163.6105

TABLE XVII
Toughened Glass Tests

Projectile: Molten Cast Iron at $1,400^{\circ}\text{C} \pm 20^{\circ}\text{C}$
Maximum Spring Tension
Height of Stop Platform: 24"

Head Size	Weight of Average Charge (grams)	Height of Specimen above Stop Platform				
		3"	4"	5"	6"	9"
Small	35	All specimens were completely shattered at each height by the three different charges.				
Medium	95					
Large	145					

TABLE XVIII
Laminated Glass Tests

Projectile: Molten Cast Iron at $1,400^{\circ}\text{C} \pm 20^{\circ}\text{C}$
Maximum Spring Tension
Height of Stop Platform: 24"

Head Size	Weight of Average Charge (grams)	Height of Specimen above Stop Platform				
		3"	4"	5"	6"	9"
Small	35	In each case the glass shattered and the laminated resin took fire.				
Medium	95					
Large	145					

TABLE XIX
Cellulose Acetate Tests

Projectile : Molten Cast Iron at $1,400^{\circ}\text{C} \pm 20^{\circ}\text{C}$
Maximum Spring Tension
Height of Stop Platform: 24"

Specimen Thickness in Thousands/inch	Results
50	Even under maximum conditions, i.e. the specimen positioned at 3 inches, and when discharging the heaviest molten metal charge, the acetate was not damaged. The metal marked the specimens and they were extremely pliable immediately after being struck, but there were no other reactions.
80	Even under maximum conditions, i.e. the specimen positioned at 3 inches, and when discharging the heaviest molten metal charge, the acetate was not damaged apart from a slight marking where it was struck by the molten metal.

TABLE XX
Allyl Resin Tests

Projectile: Molten Cast Iron $1,400^{\circ}\text{C} \pm 20^{\circ}\text{C}$
Maximum Spring Tension
Height of Stop Platform: 24"

All these specimens which were curved in the form of a meniscus lens were held in a ring which had been designed for flat specimens.

Specimen Thickness	Results
3 mm.	All the specimens remained undamaged and showed no reaction even under the maximum conditions when the heaviest molten metal charge was projected at the shortest distance of 3 inches.

TABLE XXI

*Tests of 50 mm. Specimens cut from Sheet "Cobex" Material*Projectile: Molten Cast Iron at $1,400^{\circ}\text{C} \pm 20^{\circ}\text{C}$

Maximum Spring Tension

Height of Stop Platform: 24"

Specimen Location: 3" above Stop Platform

Specimen Thickness in Thousands/inch	Average Weights of Projectiles (grams)		
	35	95	145
6	(1) Both faces scorched. Slight penetration and distortion.	(2) Metal broke through and burned top face.	(3) Complete penetration and scorching.
10	(16) Small globular penetration.	(17) Both surfaces scorched.	(18) Both surfaces scorched.
20	(31) Impacted face scorched.	(32) Impacted face scorched.	(33) Impacted face scorched.
30	(46) Impacted face slightly scorched at point of impact.	(47) Impacted face slightly scorched at point of impact. Whole specimen slightly distorted.	(48) Impacted face scorched. Top face affected. Specimen slightly distorted.
40	(61) Impacted face scorched at point of impact.	(62) Impacted face scorched at point of impact.	(63) Impacted face scorched overall.
60	(76) Impacted face scorched at point of impact.	(77) Impacted face scorched.	(78) Impacted face scorched overall.

Note: This material appears to be susceptible to smoke as in each test the whole of the impacted surface was rendered opaque until it was wiped clear at the end of the test.

TABLE XXII

Tests of 50 mm. Specimens cut from Sheet "Bexoid" Material

Projectile: Molten Cast Iron at $1,400^{\circ}\text{C} \pm 20^{\circ}\text{C}$

Maximum Spring Tension

Height of Stop Platform: 24"

Specimen Location: 3" above Stop Platform

Specimen Thickness in Thousands/ inch	Average Weights of Projectiles (grams)		
	35	95	145
5	(91) Very little effect. Specimen fired where metal stuck to holding ring.	(92) Heat penetrated and affected both faces of specimen.	(93) Specimen collapsed under the blow.
10	(106) Slight scorching of impacted face. Specimen distorted by heat.	(107) Specimen collapsed under the blow.	(108) Not tested owing to effect on 95 gram charge.
20	(121) Slight scorching of impacted face at point of impact.	(122) Slight scorching of impacted face. Specimen distorted under heat.	(123) Slight scorching of impacted face. Specimen distorted.
30	(136) Very slight scorching of impacted face at point of impact.	(137) Very slight scorching of impacted face at point of impact.	(138) Very slight scorching of impacted face. Owing to delay in removing the specimen, it was destroyed by the heat.
40	(151) Very slight scorching of impacted face at point of impact.	(152) Very slight scorching of impacted face at point of impact.	(153) Very slight scorching of impacted face. Specimen distorted.
60	(166) Very slight scorching of impacted face at point of impact.	(167) Very slight scorching of impacted face at point of impact.	(168) Very slight scorching of impacted face. Specimen distorted.

Note: This material does not scorch as badly as "Cobex" and is not susceptible to smoke, but is extremely weak under the impact of the molten metal blow.

TABLE XXIII

*Tests on Flat "Perspex" Lenses*Projectile: Molten Cast Iron at $1,400^{\circ}\text{C} \pm 20^{\circ}\text{C}$

Maximum Spring Tension

Height of Stop Platform: 24"

Specimen Location: 3" above Stop Platform

Average Weight of Projectiles (grams)	Results
35	No effect beyond a slight scorching of the impacted face.
95	Slight scorching of the impacted face and slight distortion.
145	Slight scorching of the impacted face and slight distortion.

TABLE XXIV

*Heated Projectiles*1 inch diameter solid steel ball projectile heated to 900°C

Maximum Spring Tension

Height of Stop Platform: 24"

Specimen location: 3" above Stop Platform

Specimen	Results
0.050" acetate	Slight burn mark where struck.
0.060" Cobex	Slight burn mark where struck.
0.060" Bexoid	Slight burn mark where struck.
Allyl resin lens	Slight burn mark where struck.
Perspex lens	Slight burn mark where struck.

TABLE XXV

Effects of Heat

A $\frac{1}{4}$ " diameter steel ball was heated to 900°C before being transferred from the furnace to the specimen. Two pieces of the material each 50 millimetres in diameter were used to form the specimen. The one was laid on top of the other and the top one had a $\frac{1}{4}$ " diameter hole drilled through it beforehand to enable the $\frac{1}{4}$ " diameter ball to be located on the lower specimen.

Specimen	Reaction
0.050" acetate	Ball penetrated completely in 10.5 seconds.
0.080" acetate	Ball penetrated completely in 12 seconds.
0.060" Cobex	Ball in contact for 1 minute—did not penetrate and there was no fire.
0.060" Bexoid	Ball penetrated completely in 12 seconds.

TABLE XXVI

Effects of Heat

A $\frac{1}{4}$ " diameter steel ball was heated to 900°C before being transferred from the furnace to the specimen. A small hole was countersunk in each of the specimens to the depth of approximately $\frac{1}{2}$ of the sphere of the $\frac{1}{4}$ " diameter ball.

Specimen	Reaction
Allyl resin lens	The area of the lens around the ball took fire after 10 seconds but was extinguished by normal atmospheric draught in the laboratory. The ball burned through the lens in 19 seconds.
Laminated Perspex 0.276"	The ball failed to penetrate even though left in contact until cold.
Laminated Perspex 0.305"	The ball failed to penetrate even though left in contact until cold.
Perspex lens	Ball penetrated completely in 26 seconds.

TABLE XXVII

Spring Compression Readings

Spring Compression (inches)	Load	
	lbs.	ozs.
1.5	5	8
2.0	6	8
2.5	7	8
3.0	8	8
3.5	9	8
4.0	10	8
4.5	11	8
5.0	12	8

TABLE XXVIII

Location (inches)	1	2	3	4	5
V2	30.03	77.22	141.57	223.08	321.75
V	5.48	8.78	11.89	14.97	17.93

Needle Test Machine

50 millimetre specimens cut from sheet "Bexoid"

Spring Compression (inches)	Needle Velocity (ft./sec.)	Specimen Thickness (inches)				
		0.005	0.010	0.020	0.030	0.040
1.5	6.95	Needle indentation Bulged at back	Needle indentation Bulged at back	Needle point indentation	Needle point indentation	Needle point indentation
2	8.78	Needle indentation Bulged at back	Needle indentation Bulged at back	Needle indentation Bulged at back	Needle point indentation	Needle point indentation
2.5	10.05	Needle point just penetrated. Slight indication of cracking	Needle indentation Bulged at back	Needle indentation Bulged at back	Needle indentation Bulged at back	Needle point indentation
3	11.89	Needle point just penetrated. Slight indication of cracking	Needle indentation Bulged at back. Slight indication of crack	Needle indentation Bulged at back	Needle indentation Bulged at back	Needle point indentation
3.5	13.15	Needle point just penetrated. Slight indication of cracking	Needle point just penetrated. Slight indication of cracking	Needle indentation Bulged at back Slight indication of cracking	Needle indentation Bulged at back	Needle point indentation
4	14.97	Needle point just penetrated. Slight indication of cracking	Needle point just penetrated. Slight indication of cracking	Needle indentation Bulged at back Slight indication of cracking	Needle indentation Bulged at back	Needle point indentation
4.5	16.25	Needle point just penetrated. Slight indication of cracking	Needle point just penetrated. Slight indication of cracking	Needle indentation Bulged at back Slight indication of cracking	Needle indentation Bulged at back Slight indication of cracking	Needle point indentation
5	17.93	Needle point just penetrated. Slight indication of cracking	Needle point just penetrated. Slight indication of cracking	Needle point just penetrated	Needle indentation Bulged at back Slight indication of cracking	Needle point indentation

TABLE XXX

Needle Test Machine

50 millimetre specimens cut from sheet "Cobox"

Spring Compression (inches)	Needle Velocity (ft./sec.)	Specimen Thickness (inches)				
		0.006	0.010	0.020	0.030	0.040
1.5	6.95	Needle indentation. Bulged at back.	Needle indentation. Bulged at back.	Needle point indentation.	Needle point indentation.	Needle point indentation.
2	8.78	Needle indentation. Bulged at back.	Needle indentation. Bulged at back.	Needle indentation. Bulged at back.	Needle point indentation.	Needle point indentation.
2.5	10.05	Needle point just penetrated.	Needle indentation. Bulged at back.	Needle indentation. Bulged at back.	Needle point indentation.	Needle point indentation.
3	11.89	Needle point penetrated.	Needle indentation. Bulged at back.	Needle indentation. Bulged at back.	Needle indentation. Bulged at back.	Needle point indentation.
3.5	13.15	Needle point penetrated.	Needle indentation. Bulged at back.	Needle indentation. Bulged at back.	Needle indentation. Bulged at back.	Needle point indentation.
4	14.97	Needle point penetrated.	Needle point just penetrated.	Needle indentation. Bulged at back.	Needle indentation. Bulged at back.	Needle point indentation.
4.5	16.25	Needle point penetrated.	Needle point just penetrated.	Needle indentation. Bulged at back.	Needle indentation. Bulged at back.	Needle indentation. Bulged at back.
5	17.93	Needle point penetrated.	Needle point just penetrated.	Needle indentation. Bulged at back.	Needle indentation. Bulged at back.	Needle indentation. Bulged at back.

TABLE XXXI
Needle Test Machine

50 millimetre diameter acetate specimens

Spring Compression Location (inches)	Specimen Thickness (inches)	
	0.050	0.080
1.5	Needle point indentation.	Needle point indentation.
2	Needle point indentation.	Needle point indentation.
2.5	Needle point indentation.	Needle point indentation.
3	Needle indentation. Bulged at back.	Needle point indentation.
3.5	Needle indentation. Bulged at back.	Needle point indentation.
4	Cracked right through by two cracks each approximately $\frac{1}{8}$ " long from impacted point.	
4.5	Cracked right through by two cracks each approximately $\frac{1}{8}$ " long from impacted point.	Needle point indentation.
5	Cracked right through by three cracks each approximately $\frac{1}{8}$ " long from impacted point.	Needle point indentation. Bulged at back.

TABLE XXXII
Needle Test Machine

Curved Allyl Resin Lens

Specimen	Results
1	Specimen subjected to one shot from 3". The only effect was indentation by needle point. Specimen given a further blow from 4". This second blow shattered the specimen into nine almost equal fragments.
2	Specimen subjected to one shot from 4". Specimen shattered into nine almost equal fragments exactly as specimen No. 1.

TABLE XXXIII

Needle Test Machine

50 millimetre diameter Flat Perspex Lens

Specimen	Results
1	Specimen subjected to one shot from 3 inches. The needle made slight indentation but there was no sign of cracking. Specimen then replaced in test machine and subjected to second shot from 4 inches. The needle struck exactly over the first shot and the specimen split into two almost equal parts.

TABLE XXXIV

*Needle Test Machine**Toughened Glass*

Spring Compression Location (inches)	Results
1.5	Glass slightly chipped by needle at point of impact.
2	Completely shattered.
2.5	Completely shattered.
3	Completely shattered.
3.5	Completely shattered.
4	Completely shattered.
4.5	Completely shattered.
5	Completely shattered.

TABLE XXXV

*Needle Test Machine**Laminated Glass*

Spring Compression Location (inches)	Results
1.5	No effect.
2	Needle point marked glass.
2.5	Both glasses cracked, and small splinters came off back face.
3	Both glasses cracked, and small splinters came off back face.
3.5	Both glasses cracked, and small splinters came off back face.
4	Both glasses cracked, and small splinters came off back face.
4.5	Both glasses cracked, and small splinters came off back face.
5	Both glasses cracked, and small splinters came off back face.

APPENDIX II

A LABORATORY BALLISTIC TRIAL OF GOGGLE LENSES

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CONTENTS

	Page
INTRODUCTION	58
EXPERIMENTAL WORK	58
Materials	58
Laboratory Test	59
RESULTS	60
Selection of Lenses: Results of Tests	60
Results of Ballistic Tests of Lenses Using Samples No. 7 and No. 8	62
Results of Assessment of Velocity at Impact	62
DISCUSSION	62
CONCLUSIONS	64
TABLES	65

A LABORATORY BALLISTIC TRIAL OF GOGGLE LENSES

INTRODUCTION

1. The object of the work was to investigate the impact strength of various lenses and select from them by ballistic trial the one most suitable as a replacement in an existing type of goggles.

EXPERIMENTAL WORK

2. Materials

(a) *Description of existing equipment*

The existing equipment consisted of a pair of goggles having $\frac{3}{8}$ " perspex lenses fitted into an aluminium alloy frame. Each lens consisting of a front and side was constructed in one piece, chamfered on the inside, and bent over at right angles to give a smooth and bevelled corner junction. This method of joining has the marked advantage of retaining the maximum field of view through the lens, the junction appearing as a thin line. This is in marked contrast to the obscuring bar due to refraction obtained when the front and side pieces of the lens meet at right angles without a 45° facing bevel. The goggles were designed to fit all facial contours and had vent holes on the side portion of the lens and on top and bottom of the alloy frame, inclined to the rear to prevent grit and sand entering the eyes directly as a result of an explosion. The head harness was adjustable and could be fitted over small ordinary spectacles. The weight of the goggles was four ounces.

(b) *New lenses*

After examination of several materials suitable for lenses, it was decided to investigate ballistically various types of lenses in laminated glass and laminated perspex. Messrs. Triplex Safety Glass Co. Ltd., were approached and through their very kind co-operation and generosity, the following lenses, six of each, cut to the shape of the front piece of the goggle frames, were obtained for test purposes:

- (1) 3-ply Triplex glass with 30/1000" soft "vinal" in each laminated bevelled but not notched. (Thickness=0.215").
- (2) 2-ply $\frac{1}{8}$ " toughened laminated glass with 45/1000" soft "vinal" bevelled and notched. (Thickness=0.270").
- (3) 2-ply $\frac{1}{8}$ " toughened laminated glass with 45/1000" soft "vinal" not bevelled and not notched. (Thickness=0.266").
- (4) 2-ply laminated perspex with $\frac{1}{8}$ " soft "vinal" interlayer, bevelled and notched. (Thickness=0.286").
- (5) 2-ply perspex with 30/1000" soft "vinal" interlayer, bevelled and notched. (Thickness=0.285").
- (6) 2-ply perspex with 60/1000" soft "vinal" interlayer, bevelled and notched. (Thickness=0.295").

- (7) 3-ply perspex with 30/1000" soft "vinal" interlayer, bevelled and notched. (Thickness=0.3125").
- (8) 3-ply perspex with 60/1000" soft "vinal" interlayer, bevelled and notched. (Thickness=0.295").

The firm was asked not to exceed $\frac{1}{16}$ " for the overall thickness of the lenses. To achieve this, the perspex thickness was varied to accommodate the varying thicknesses of the "vinal" interlayer. The firm used its own methods for bonding the interlayers of "vinal" with the glass and the perspex.

3. Laboratory Test

The trial was conducted in two phases:

- (a) The selection of the two best types of lenses of the eight available by a comparative ballistic test, and
- (b) A repeat of the ballistic test with the chosen lenses fitted in the goggles, replacing the original lenses of single thickness of perspex, with a view to selecting the best type.

(a) *Methods of selection of lenses*

The ballistic test required had to be reasonably consistent in velocity up to 1,000 feet per second and the missile had to be fired with fair accuracy, the target lens being approximately 2" x 2". Advice was sought from various authorities on how best to conduct the ballistic test with a low velocity fragment simulating projectile. In the interest of consistency, it was eventually decided to use a steel cube as the missile, this being possibly closest to a "standard" fragment. A weight of 17 grains (about 1 gramme) was chosen to be in line with the projectile used in the test in which the original lens failed. Helpful suggestions were obtained from many sources but it was disappointing to learn that there was no available technique in current use which could produce sufficient accuracy at the low velocities required with the type of projectile proposed. Facilities to carry out the tests were very kindly given by the Fighter Development Branch of the Royal Aircraft Establishment and that Branch also provided the invaluable aid of a Range Officer of long experience. Various weapons were tried including the 0.303 rifle, a revolver, a saloon rifle, and a shot-gun with cartridges variously loaded and using different explosives before finally deciding on the 0.410 shot-gun as the most appropriate for the test. Messrs. I.C.I. Limited very kindly provided all the ammunition, except the missiles, in broken down form together with a crimping tool for sealing the cartridge. Coarse black powder was used as the propellant.

The cartridge was loaded as follows:

A measured quantity of powder, very small in relation to the size of the cartridge, was put in the case first followed in turn by an air-cushion wad, a cardboard cylindrical distance piece, a further wad with the missile centred on it in a small blob of wax and a final cylindrical distance piece to take up the remaining space to the head of the case. The cartridge was then closed in the vice using the crimping tool. To ensure comparable closure the case was placed in an aluminium alloy sleeve which in turn fitted into a socket suitably recessed to prevent the cap of the cartridge firing when the vice was closed on the assembly. The vice was turned until the crimping tool reached the top of the sleeve.

Initially with the above loading of the cartridge the wads were troublesome "following on" behind the missile and wrecking the timing screens. Velocity was measured over a time base of three feet, the time being recorded on a Decimal Counter Chronometer Type IA.Mk.1. The Counter was started by the missile breaking a copper wire three inches in front of the muzzle and stopped by breaking a further grid of wires six inches in front of the target. To get rid of the wads an armoured plate was incorporated in the rig with a hole in it sufficient in size to allow the passage of the projectile but not the wads. The Counter "starting" wire was lined across the back of the hole. Velocity values determined from the Counter were shown to be higher than the actual striking value by about four feet per second.

The target lenses were mounted in a wooden structure which could be dismantled by means of fly nuts after the lenses had been fired at, and allow of close examination of damage to the lens in situ. Splinters and fragments thrown off from the back of the lens, as a result of the impact, were caught on a plasticine layer approximately one inch behind the lens. All shots were fired at normal incidence to the target.

To get some idea of the damaging effect of the splinters thrown off from the lens further tests were done with a pig's eye mounted in the wooden structure in lieu of the plasticine and successive shots were fired at the No. 8 perspex, the No. 2 toughened glass and the No. 1 Triplex lens. All shots were again at normal incidence.

(b) Method of Ballistic Testing with the New Lenses

Messrs. Triplex Safety Glass Company Limited were commissioned to replace the lenses of the old goggles with the two new types. 24 pairs of goggles, twelve of each type were obtained.

A metal alloy head was borrowed from Chemical Defence Experimental Establishment and orbits were drilled out in it comparable in size to an average human orbit. The artificial orbits were filled initially with plasticine, but later with real eyes. Pig's eyes were chosen because of their availability and their relative correspondence in size to human eyes. It was felt that using them as a target in the metal head would give a more realistic picture than would plasticine of the possible damage to the human eyes from the flying perspex fragments.

In some tests ordinary spectacles fitted with plain glass lenses were placed on the metal head over the pig's eyes and under the goggles to prevent direct entry of splinters into the eyes. Further tests were carried out with the original goggles in position on the full "head" rig and later with No. 8 lens goggles positioned on the head without spectacles behind. All shots were fired at normal incidence. It was hoped to get direct comparison of resistance to impact of each type of lens.

RESULTS

4. Selection of Lenses: Results of Tests

Using a standardised technique each cartridge was hand-made with a weighed quantity of coarse black powder as a propellant. Successive shots with the same weight of propellant could not be relied on closer than ± 100 ft./sec. of the average velocity for that weight of charge. Accuracy in the main was good with

an occasional "wild" shot possibly due to the missile touching the hole in the armour plate on its way through.

All lenses were completely penetrated at velocities of 1,000 feet per second. The following results are based on a minimum of 4 and a maximum of 6 shots per type of sample lens:

Sample No. 1

Triplex glass 0.215" thick. Complete penetration at 718 feet per second. The penetration was accompanied by a shower of glass splinters which lodged in the plasticine placed behind the lens at 1" distance.

Samples No. 2 and 3

Laminated toughened glass. 0.270 and 0.266" thick respectively. The "vinal" interlayer could withstand without penetration velocities up to 860 feet per second. There was however an accompanying mass of glass splinters which were thrown off from the layer next to the eye sufficiently fast to smash a glass lens placed between the toughened glass and the plasticine eye. This ruled out toughened glass as a possible substitute lens.

Samples No. 4, 5 and 6

Laminated perspex 0.286, 0.285 and 0.295" thick respectively. Of this trio Sample No. 4 had most potential as a lens. The thick $\frac{1}{2}$ " soft "vinal" interlayer of the sample had more stopping power than the thinner "vinal" of the other two. From all of them large fragments were thrown off on impact, Sample No. 4 producing the largest in fragment size. No. 4 was not penetrated at a velocity of 812 feet per second, but threw off a splinter which embedded itself in the plasticine eye to a depth of $\frac{1}{8}$ ". No. 5 was completely penetrated at 770 feet per second and No. 6 at 743 feet per second.

Samples No. 7 and 8

3-ply perspex 0.3125 and 0.295" thick respectively. The splinters thrown off from these samples after impact were smaller and fewer and the general shattering was less than in any of the other samples. No fragments of any size were thrown off at velocities up to 700 feet per second when the lens was hit centrally and generally only very small fragments which lay loosely on the plasticine were thrown off up to 800 feet per second. A test was carried out with a glass lens between the perspex and the plasticine at 735 feet per second. The glass lens was undamaged and stopped the few splinters of perspex which were thrown off. In this part of the trial partial penetration with few splinters were obtained with velocities up to 812 feet per second.

The individual results of the tests, using a pig's eye in lieu of plasticine, are shown in Table I. In the case of the No. 8 lens the few splinters which alighted on the eye could be blown or washed off. The splinters from the No. 2 lens, toughened glass, cut the outer mucosa of the eye very badly. The Triplex lens No. 1 was completely penetrated, the projectile completely destroying the eye. The splinters following behind penetrated the outer layer and entered into the aqueous humour.

In view of the relatively small number of fragments thrown off and the reduction in the general shattering it was decided to have 24 pairs of goggles made up with the sample lenses No. 7 and 8 for further tests.

5. Results of Ballistic Tests of Lenses Using Samples No. 7 and No. 8

The rig used is described in paragraph 3, and individual shots are recorded in Table II. All shots were fired at normal incidence to the lenses.

At comparable velocities (Serial Nos. 5, 7, 13, 25, 29 and 31 in Table II) the tests showed that the No. 7 lens was subject to deeper penetration by the missile with more accompanying and damaging splinters when hit than the No. 8 lens.

There were more instances of the No. 7 than of the No. 8 lens being torn off its rivets by the impact and of the glass lens of the spectacle behind being broken (see Serial Nos. 7, 8, 9 and 13). With the smaller number of samples it is difficult to draw conclusions from this, but there was only one instance of the No. 8 lens being torn off its rivets (Serial No. 18). Unfortunately the chronometer failed on the latter shot so that the velocity could not be calculated. From observations of the effect of the missile on the lenses after every shot, it was quite clear that the lens No. 7 was more subject to damage than No. 8 at comparable velocities.

The missile on the original goggles (Table I, Serial Nos. 5 and 6 at 597 and 852 feet per second) smashed the goggle lenses and the spectacle glass to pieces, the projectile penetrating to the base of the pig's eye and only being stopped by the base of the metal socket. Of the two shots at the No. 8 lens without spectacles behind them, one completely penetrated at 785 feet per second the lowest velocity with complete penetration, which occurred on this lens. The missile struck the goggle lenses in the area of the eye rivets and just penetrated. The splinters thrown off did not penetrate the eye and were washed off. The velocity of the other shot was low, but tiny splinters which were washed off did alight on the eye.

6. Results of Assessment of Velocity at Impact

Two chronometers were used on the normal rig except that a wire grid replaced the normal target position. The first chronometer was connected to the "start" wire behind the hole in the armoured plate and to the "stop" wires 6 inches in front of the target over a time base of 3 feet. The second chronometer was also connected to the "start" wire but its "stop" wires were in the target position giving it a time base of 3 feet 6 inches. The chronometers had been checked against each other prior to the experiment being connected to the same "start" and "stop" wires. Over several tests they agreed to .00001 of a second. Results obtained from calculations using the two chronometers on different time bases indicated that the velocity at impact could be taken as being approximately 4 feet per sec. less than that calculated from the time base.

DISCUSSION

7. The small amount of data from the present trial revealed from the beginning that not only is there the problem of stopping a metal particle but there is also the very real secondary hazard of preventing splinters from entering the eye from the back of a lens which has been hit. In these trials ordinary spectacles with plain glass lenses were used in some cases in conjunction with the goggles.

The experiment showed that direct entry of a lens splinter into the eye could be stopped by intervening spectacles but that ricochets off the side lens entered the eye on many occasions. None of the perspex splinters from lenses 7 or 8 embedded themselves in the pig's eye.

8. The cube shape of projectile was used in preference to a ball on the grounds that it more closely resembled a real fragment having sharp edges and corners. There is some evidence from other workers that up to the order of 1,000 ft./sec. against non-metal targets the initial tumbling tearing action of the cube appears to give it more penetrating power than a steel ball. It was considered that its use, despite its ballistic shortcomings of variation in presented area, gave a test much more rigorous in its effect on the lenses than a ball.

9. The laminated glass lenses were ruled out because of the relatively low resistance to penetration. Toughened glass which has high resistance failed because of its complete disintegration when struck and the accompanying mass of glass splinters which were thrown off sufficiently fast to smash a spectacle lens of ordinary glass one inch behind it. When no intervening spectacle glass was used the mass of fine splinters from the toughened glass badly cut the cornea of the pig's eye again situated at one inch distance from the goggle lens (Table I, Serial No. 3). Of the various types of laminated perspex tested three-ply was best since it produced fewer and smaller splinters which could be stopped by suitable spectacles as well as having more resistance than any of the others.

10. The test on the goggles fitted with lenses No. 7 and 8 showed that there was deeper penetration of the lens by the missile with more accompanying splinters with No. 7 than with No. 8 lens at comparable velocities. From the figures in Serial Nos. 1 to 32 in Table II there does not appear to be much to choose between them, but from observation of the effect on the lenses after every shot it was quite clear that the lens No. 7 was the one more subject to damage.

11. For both types of lenses the area near the nose was most vulnerable and complete penetration was effected there with a velocity of 785 feet per second (Table I, Serial No. 8) on a No. 8 lens. This was the only case of complete penetration of a No. 8 lens, apart from one at 1,000 feet per second recorded during the trial and was in contrast to a single shot of 912 feet per second which was successfully held (Serial No. 30, Table II).

12. The highest recorded velocity for the No. 7 lens without penetration was a central hit of 895 feet per second (Table II, Serial No. 4) but later one of 795 feet per second also central on the lens was virtually through the lens.

13. Optically the No. 7 lens is slightly superior in quality to No. 8 presumably because of its thinner "vinal" interlayer. It is considered however that the No. 8 lens is still sufficiently good in optical quality for certain tasks.

14. Lack of sufficient numbers of lenses, the difficulty of the technique and the time involved in carrying it out prohibited extensive experimental work to obtain enough data on the limiting velocities (i.e. for complete penetration) for each lens and establish statistically which of the two was the superior. However, it is deemed that the experiments were carried sufficiently far to produce convincing evidence to the observers that of all the lenses tested Nos. 7 and 8 of three-ply perspex were the best and of them No. 8 was to be preferred for stopping flying fragments (see Figure 13).

CONCLUSIONS

15. The three-ply perspex lens with interlayers of 60/1000" soft "vinal" and overall thickness of 0.295" has the best impact strength against flying fragments of the lenses tested.
16. With the exception of a small area in the region of the nose rivets of the goggles this lens can withstand an impact from a 17 grain steel cube fragment simulating projectile at velocities up to 850 feet per second at normal incidence without complete penetration.
17. There is no flaking from the chosen goggles lenses up to about 600 ft./sec. and up to 850 ft./sec. all fragments alighting on the eye could be washed out of the eye or blown off.

TABLE I

Further tests were done with (a) a No. 8 lens fitted on the original "wooden" rig in front of a pig's eye, with no intervening glass spectacles, and (b) a repeat of (a), with a No. 2 lens (laminated toughened glass) and a No. 1 lens (Triplex) in place of the No. 8 lens; (c) the original goggles in position on the full "head" rig; and (d) the No. 8 lens goggles positioned on the head, without spectacles behind. The following results were obtained:

Serial No.	Weapon and rig used	Charge	Time base	Chronometer reading in seconds	Lens	Muzzle velocity	Accuracy	Remarks
1	0.410 Shotgun Wooden structure and pig's eye	0.32 gms. Black Powder	3 ft.	0.00419	No. 8	716 ft./sec.	Poor	No penetration; projectile bounced off; splinters on eye, which washed off.
2	0.410 Shotgun Wooden structure and pig's eye	0.32 gms. Black Powder	3 ft.	0.00396	No. 8	757 ft./sec.	V. good	Dead centre of perspex. No penetration; projectile bounced off; few splinters on eye, which washed off.
3	0.410 Shotgun Wooden structure and pig's eye	0.32 gms. Black Powder	3 ft.	0.00416	No. 2 Toughened glass	722 ft./sec.	V. good	Projectile bounced off; masses of glass splinters impinged on the eye and badly cut the mucosa, but there was no leakage of aqueous humour.

TABLE I (contd.)

Serial No.	Weapon and rig used	Charge	Time base	Chronometer reading in seconds	Lens	Muzzle velocity	Accuracy	Remarks
4	0.410 Shotgun Wooden structure and pig's eye	0.32 gms. Black Powder	3 ft.	0.00349	No. 1 Triplex	862 ft./sec.	Fair	Low shot which completely penetrated, throwing splinters into the eye which was already destroyed by projectile.
5	0.410 Shotgun Head rig and pig's eye	0.32 gms. Black Powder	3 ft.	0.00352	Original $\frac{1}{8}$ " Perspex	852 ft./sec.	V. good	Perspex lens and spectacle lens smashed to pieces. Projectile penetrated to base of the eye socket and was stopped by metal of the head.
6	0.410 Shotgun Head rig and pig's eye	0.2 gms. (approx.)	3 ft.	0.00504	Original $\frac{1}{8}$ " Perspex	597 ft./sec.	Fair	Low shot; perspex lens and spectacle lens smashed; projectile penetrated through the eye to the metal base.
7	0.410 Shotgun Head rig and pig's eye	0.32 gms.	3 ft.	0.00443	No. 8	677 ft./sec.	Good	No spectacles were used. A very few tiny splinters were thrown off which impinged on the eye but they could be washed off. No penetration.
8	0.410 Shotgun Head rig and pig's eye	0.32 gms.	3 ft.	0.00384	No. 8	785 ft./sec.	Fair	Projectile struck the lens close on the nose side and just penetrated, throwing the splinters into the eye; none of which penetrated the eye.

TABLE II

Serial No.	Weapon and rig used	Charge	Time base	Chronometer reading in seconds	Lens	Muzzle velocity	Accuracy	Remarks
1	0.410 Shotgun	0.32 gms. Black Powder	3 ft.	0.00338	7	885 ft./sec.	Poor	High shot. Deep but partial penetration.
2	0.410 Shotgun	0.32 gms. Black Powder	3 ft.	0.00667	7	430 ft./sec.	V. Poor	Projectile hit junction of front and side lens. No penetration.
3	0.410 Shotgun	0.32 gms. Black Powder	3 ft.	0.00373	7	804 ft./sec.	V. Good	Projectile bounced off. Splinters held by spectacles.
4	0.410 Shotgun	0.32 gms. Black Powder	3 ft.	0.00337	7	890 ft./sec.	V. Good	Projectile bounced off. Small splinters held by spectacles.
5	0.410 Shotgun	0.32 gms. Black Powder	3 ft.	0.00363	7	827 ft./sec.	V. Good	Projectile penetrated to last layer and splinters of perspex broke spectacles glass and lodged on the eyeball quite loosely.
6	0.410 Shotgun	0.32 gms. Black Powder	3 ft.	0.00379	7	792 ft./sec.	Good	Many splinters in bulk were thrown off. Projectile was held in the perspex; few splinters ricocheted on to eyeball.
7	0.410 Shotgun	0.32 gms. Black Powder	3 ft.	0.00360	7	833 ft./sec.	Good	Partial penetration of perspex but the lens was broken away from its rivets and smashed the glass of the spectacles behind. The eye was not punctured.
8	0.410 Shotgun	0.32 gms. Black Powder	3 ft.	0.00405	7	740 ft./sec.	Good	Again lens forced off rivets. Splinters, but none on the eye.

TABLE II (contd.)

Serial No.	Weapon and rig used	Charge	Time base	Chronometer reading in seconds	Lens	Muzzle velocity	Accuracy	Remarks
9	0.410 Shotgun	0.32 gms. Black Powder	3 ft.	0.00507	7	593 ft./sec.	Poor	No penetration. Projectile hit edge at junction of front and side pieces; the side lens came adrift. Splinters on the eye washed off.
10	0.410 Shotgun	0.32 gms. Black Powder	3 ft.	0.00399	7	753 ft./sec.	Good	Partial penetration. Splinters larger than usual thrown off. One ricocheted on to the eye. Spectacles were not damaged. The splinter on the eye was blown off.
11	0.410 Shotgun	0.32 gms. Black Powder	3 ft.	0.00405	7	742 ft./sec.	Good	Partial penetration. Projectile was deeply wedged in the perspex. Splinters ricocheted on to the eye. Spectacles lost a small glass splinter at the rim.
12	0.410 Shotgun	0.32 gms. Black Powder	3 ft.	0.00359	7	837 ft./sec.	V. Good	Central hit; partial penetration; few splinters; none on eye. Spectacles undamaged.
13	0.410 Shotgun	0.32 gms. Black Powder	3 ft.	0.00369	7	814 ft./sec.	Poor	Projectile hit junction of frame and perspex at the top. It split perspex away from rivets but was held. Spectacles were not broken. Splinters on the eye were washed off.
14	0.410 Shotgun	0.32 gms. Black Powder	3 ft.	0.00443	7	677 ft./sec.	Good	Partial penetration; few splinters; none on the eye.
15	0.410 Shotgun	0.32 gms. Black Powder	3 ft.	0.00395	7	760 ft./sec.	V. Good	Projectile bounced off. There were many splinters; a few ricocheted on to the eyeball; they washed off.
16	0.410 Shotgun	0.32 gms. Black Powder	3 ft.	0.00378	7	795 ft./sec.	V. Good	Projectile almost through. Splinters ricocheted on to the eye. Spectacles were unbroken. Splinters were washed off.

TABLE II (contd.)

Serial No.	Weapon and rig used	Charge	Time base	Chronometer reading in seconds	Lens	Muzzle velocity	Accuracy	Remarks
17	0.410 Shotgun	0.32 gms. Black Powder	3 ft.	0.00335	8	896 ft./sec.	V. Good	Partial penetration. Projectile held in perspex. Tiny splinters very loose on the eye.
18	0.410 Shotgun	0.32 gms. Black Powder	3 ft.	Chronometer failed	8	—	V. Good	The projectile tore the lens off its rivets, near the nose, and the lens smashed the glass of the spectacles behind. The perspex was not penetrated.
19	0.410 Shotgun	0.32 gms. Black Powder	3 ft.	0.00450	8	667 ft./sec.	Good	The projectile bounced off. There were no splinters behind.
20	0.410 Shotgun	0.32 gms. Black Powder	3 ft.	0.00331	8	906 ft./sec.	Good	Partial penetration, but splinters ricocheted on to the eyeball. Spectacles undamaged. Splinters were blown off the eyeball. Two of the splinters were quite large and triangular.
21	0.410 Shotgun	0.32 gms. Black Powder	3 ft.	0.00418	8	716 ft./sec.	V. Good	Projectile bounced off. Tiny splinters ricocheted on to eyeball. Spectacles undamaged. Splinters blown off eyeball.
22	0.410 Shotgun	0.32 gms. Black Powder	3 ft.	0.00466	8	643 ft./sec.	V. Good	Projectile bounced off. No splinters.
23	0.410 Shotgun	0.32 gms. Black Powder	3 ft.	0.00445	8	675 ft./sec.	V. Good	Partial penetration. Projectile bounced off. Small splinters.
24	0.410 Shotgun	0.32 gms. Black Powder	3 ft.	Chronometer failed	8	—	Good	Projectile deep in the perspex. Tiny splinters on the eye. Spectacles intact. Splinters blown off.

TABLE II (contd.)

Serial No.	Weapon and rig used	Charge	Time base	Chronometer reading in seconds	Lens	Muzzle velocity	Accuracy	Remarks
25	0.410 Shotgun	0.32 gms. Black Powder	3 ft.	0.00356	8	845 ft./sec.	Good	Partial penetration. Projectile held. Splinters very small. Few on the eye were washed off. Spectacles intact.
26	0.410 Shotgun	0.32 gms. Black Powder	3 ft.	0.00553	8	532 ft./sec.	Good	Central hit. The side lens cracked. No penetration. No splinters.
27	0.410 Shotgun	0.32 gms. Black Powder	3 ft.	0.00422	8	712 ft./sec.	Good	Partial penetration; few splinters; none on the eye; projectile bounced off.
28	0.410 Shotgun	0.32 gms. Black Powder	3 ft.	Chronometer failed	8	—	V. Good	Complete penetration. Projectile inside protectors. Spectacles still intact; eye undamaged.
29	0.410 Shotgun	0.32 gms. Black Powder	3 ft.	0.00370	8	812 ft./sec.	V. Good	Partial penetration; central hit; projectile held; splinters few.
30	0.410 Shotgun	0.32 gms. Black Powder	3 ft.	0.00329	8	912 ft./sec.	V. Good	Partial penetration; large splinters inside protectors; none on the eye; spectacles undamaged.
31	0.410 Shotgun	0.32 gms. Black Powder	3 ft.	0.00354	8	847 ft./sec.	V. Good	Partial penetration; central hit; fragments ricocheted on the eye; blown off; spectacles intact.
32	0.410 Shotgun	0.32 gms. Black Powder	3 ft.	0.00338	8	887 ft./sec.	V. Good	Projectile just held in the perspex. Splinters thrown off which ricocheted on to the eyeball; washed off; no damage to spectacles.

APPENDIX III

CONTENTS

	Page
Second Interim Report of the Joint Advisory Committee on Foundry Goggles	72
Second Interim Report of the Sub-Committee of the Joint Advisory Committee on Foundry Goggles	73
Membership of the Sub-Committee of the Joint Advisory Committee on Foundry Goggles	73
INTRODUCTION	74
PRELIMINARY CONSIDERATIONS	75
General	75
Molten Metal Tests	76
Hot Metal Tests	76
Nature of Projectiles	77
Needle Tests	77
Existing Information	77
IMPACT TESTING	77
General	77
Proposed Methods of Testing	78
Air Rifle Test Rig	78
Calibration	80
Test Procedures	80
Results of Impact Tests	82
BURNING TESTS	82
Equipment	82
Results	83
NEEDLE TESTS	83
GOGGLE TESTING	83
CONCLUSIONS	83
ACKNOWLEDGMENTS	84
TABLES	85

SECOND INTERIM REPORT OF THE JOINT ADVISORY COMMITTEE ON FOUNDRY GOGGLES

Mr. T. W. McCullough, O.B.E.

H.M. Chief Inspector of Factories

1. We have received this Second Report from our Technical Sub-Committee describing a considerable amount of new work on the testing of materials for goggle lenses. We have accepted the Report and decided to present it to you at once, because it represents the completion of the second phase of the work of the Sub-Committee.

2. The Sub-Committee has designed, constructed and used a new type of test rig; concluded a series of tests; found certain materials which withstand the test; and confirmed and amplified their earlier conclusions.

Preliminary work has also been done on certain ophthalmological aspects of the selected materials by Mr. Weston and we have good reason to believe that the materials will satisfy the British Standard requirements in this respect.

3. We have asked the Technical Sub-Committee to proceed now with the third phase of their work, and this is in fact already in progress. It involves the design and construction of another test rig on which complete goggles, spectacles or face screens can be tested, so that the performance of the actual articles as worn can be judged.

4. You arranged for our First Report to be published in full in the Foundry Trade Journal and we noted this with satisfaction. We understand that similar publicity may follow for this Second Report, a course which we would approve. There is now every reason for the makers and users of all forms of eye protection for use in foundries in particular, and in industry generally, to be aware of the findings of the Sub-Committee and for makers to proceed at once with such research and development in co-operation with this Committee as will ensure early commercial production of eye protection on the basis of the information now available.

5. We are most grateful to the Technical Sub-Committee for the work which has been done.

(Signed) R. BRAMLEY-HARKER (*Chairman*)

R. BERRY

A. W. BUSHELL

G. P. CROWDEN

J. GARDNER

J. HIGHAM

W. B. LAWRIE

H. V. SHELTON

A. H. SULLY

T. A. SWINDEN

H. C. WESTON

S. G. RAINSFORD

2nd March, 1959

**SECOND INTERIM REPORT OF THE SUB-COMMITTEE OF
THE JOINT ADVISORY COMMITTEE ON FOUNDRY GOGGLES**

Members of Sub-Committee

Mr. A. W. Bushell

Mr. W. B. Lawrie, M.B.E., M.Sc., F.R.M.S., A.I.M.

SECOND INTERIM REPORT OF THE SUB-COMMITTEE OF THE JOINT ADVISORY COMMITTEE ON FOUNDRY GOGGLES

*Mr. R. Bramley-Harker,
Chairman,
Joint Advisory Committee on Foundry Goggles*

INTRODUCTION

1. We have now reached the end of the second stage of the work that was remitted to us by the Joint Advisory Committee on Foundry Goggles, and so we are offering you a second report even although this may not yet be a final one. This second report deals chiefly with the strength of the plastic materials of which lenses may be made, although we have done some very preliminary work on full goggles and by this time we have begun to think about the construction of goggles or spectacles. This report does not deal with ophthalmological aspects of the problem, even though early work is already in hand.

2. As a matter of convenience we quote here the conclusions we had reached at the end of the first phase of our work and which we embodied in Section 36 of our first report which read as follows:

" 36. The work has not yet been completed but sufficient has been done to lead us to certain definite conclusions.

- (a) Toughened glass should not be used as protection against molten metal, nor should it be used to protect against flying particles in foundries.
- (b) Laminated glass is always broken by the molten metal and often broken by flying particles. In some cases splinters fly off from the surface of the laminated glass that would be adjacent to the wearer's eyes. It could not be said that laminated glass is useless, but those of us who have seen the experimental work would not be comfortable again in using this material. We hold the view therefore that laminated glass should not be used in foundries.
- (c) Plastics are greatly superior to glass in resisting penetration by molten metal. Much more work needs to be done in order to determine the suitability of the various plastics for use as goggles, but there can be no doubt that suitably designed plastic goggles are infinitely better than glass goggles in resisting penetration, either by molten metal or by flying fragments.
- (d) The tests available show that a laminated plastic goggle was by far the best so far as physical protection is concerned. Many more aspects of the matter will have to be considered and much more work will have to be done, but the experimental work to date indicates quite clearly that the laminated plastic goggle is the one that provides the maximum degree of safety.

- (e) Molten metal does not appear to wet plastic surfaces but it does wet metal surfaces and glass surfaces and adheres to them. It appears at this stage, therefore, that plastic lenses should not be mounted in metal rims, because molten splashes will adhere to the rim and may then set fire to the plastic. This aspect of the matter clearly needs further consideration and probably further experimental work."

3. These conclusions were quite definite and have remained unaffected by our subsequent work. What we have done is to amplify them in certain respects and to obtain a good deal more information in the particular range of protection which we think desirable in foundries.

We considered conclusions (a) and (b) to be definite and final because at the time of our first report we had already discarded glass in any form for foundry work where eye protection should be adequate to withstand molten splashes and hot and cold solid particles all at high impact values. We have, however, tested toughened and laminated glass specimens in the new test rig, and as we expected they failed utterly, the lenses shattering and disintegrating completely as they were penetrated by the projectiles.

Conclusion (e) concerns the construction of goggle or spectacle frames and we have not yet investigated this matter in detail.

This second report, therefore, deals mainly with conclusions (c) and (d).

PRELIMINARY CONSIDERATIONS

General

4. We drafted our first report at the end of the first phase of the work when we had

- (a) designed, constructed, calibrated and used a spring loaded test machine with cold solid projectiles, hot solid projectiles and molten metal projectiles, striking the lenses under test at velocities of 7 to 10 feet per second;
- (b) examined the work of Major Reid who had designed, constructed, calibrated and used a rig with cold solid projectiles striking the lenses under test at velocities of 700 to 900 feet per second;
- (c) designed, constructed, calibrated and used a needle test machine; and
- (d) completed preliminary burning tests on certain plastic specimens.

We had, so far as impact testing is concerned, also expressed the view that a test machine should be designed and constructed that would allow of all specimens to be penetrated so that the various specimens could be arranged in order of merit. We still think this to be the ideal method, although we have not yet succeeded in devising such a machine. In fact our work indicates that the range of protection that is available with plastic materials may be so great that it will be no easy matter to devise a single impact testing machine capable of projecting a missile over the necessary range of speeds.

5. We had also decided for practical reasons that we should look for protection against the high velocity particles that might be projected across a foundry. Cut-off wheels may run at peripheral velocities up to 20,000 feet per minute, and if they break the fragments leave the wheel at this initial velocity. We have seen

no reason to change our original decision and, although we make no suggestions as to whether or not 20,000 feet per minute is either a common velocity or a maximum velocity, we think it reasonable to use it as a known actual velocity against which eye protection should suffice.

6. We began this second phase of our work, therefore, with information covering cold solid, hot solid and molten projectiles at velocities between 7 and 10 feet per second and cold solid projectiles at speeds between 700 and 900 feet per second. Ideally, we needed tests which would indicate the behaviour of goggle lenses at all intermediate speeds, but specifically we wanted to know what happened at about 20,000 feet per minute, i.e. about 350 feet per second. This meant that the first problem we had to solve was the design of a suitable test machine, because the spring operated machine we had used for low velocity tests could not be lifted, and the rig used by Major Reid for the high velocity tests could not be brought down to the speed range we needed.

Molten Metal Tests

7. The results of our work with molten metal projectiles had shown that glass always cracked on impact and that plastic materials were frequently undamaged. It was evident that the effects of heat and impact on the specimen could be separated. However light the blow, glass cracked because the molten metal adhered to the specimen and the rapid expansion following the heat transfer from projectile to specimen cracked the glass. Plastic specimens were never damaged by the heat of the projectile. This appeared to be due to the fact that the molten metals used did not adhere to the plastic specimens but splashed away from them. The molten projectiles were therefore in contact with the plastic specimens for so short a time that insufficient heat was transferred from projectile to specimen to damage the latter. Clearly heat transfer is a function of the time during which projectile and specimen are in contact. This time, with glass lenses, is the time taken for the projectile to cool because the molten metal projectiles adhere to the glass, but with plastics, where the molten projectile splashes away from the specimen, the time is very short. It is also a function of the speed at which the specimen was struck by the projectile. So long as the specimen withstands the blow the faster the molten projectile strikes, the faster will it rebound. So that with molten projectiles against plastic lenses, the heat transferred from projectile to specimen varies inversely with the projectile velocity. This means that so far as the effects of heat are concerned the high speed molten projectile does less damage to a plastic specimen than the low speed molten projectile or, in other words, the most severe tests result from the lowest speeds. We had already completed molten metal tests on the spring operated machine at speeds between 7 and 10 feet per second, and as these low speed tests represented more severe conditions than higher speeds would give we decided to do no more molten metal tests. Obviously when we knew that plastics withstood the heat in the more severe condition, there was no point in testing again under less severe conditions.

Hot Metal Tests

8. The above argument holds for molten metal projectiles and for hot solid projectiles so long as the latter bounce from the specimen. In either case the faster the initial impact the shorter the time of contact and so the smaller the amount of heat transferred to the specimen.

This is not true, however, of hot solid projectiles which embed themselves in the plastic lens when the impact has been insufficient to break the lens. In this case heat will be transferred to the lens which will be damaged by this heat—damage, that is, in addition to the damage already produced by the impact of the projectile. It is obviously a matter of some importance that lenses with a red hot projectile embedded in them should neither take fire nor melt in so short a time that the wearer is unable to remove the spectacles from his face before suffering injury.

We decided therefore that we must persist in tests designed to indicate the influence of heat on the plastic specimens and we have in consequence continued the relevant series of tests which we had started when we submitted our first report.

Nature of Projectiles

9. The foregoing considerations led us to the view that impact could be tests done with cold solid projectiles so long as other tests had provided sufficient information about the effects of heat as distinct from the effects of impact. We therefore discontinued molten metal tests and having reached this decision proceeded straight to the use of solid projectiles because we could see no virtue in using any liquid projectile after we had discarded molten metal for impact purposes.

Needle Tests

10. We decided to continue the use of the needle machine described in our first report.

Existing Information

11. Before proceeding with the design of a suitable machine for testing impact values, we approached certain manufacturers of plastics in the hope that sufficient information might be forthcoming to allow us to calculate, or estimate, the strength of the various kinds of material. Unfortunately this information was not available and we were also informed that it would not be practicable to take results from plain sheet material and extrapolate them to laminated material. It was evident, therefore, that we must proceed to the design and construction of a machine which would enable us to procure the results we needed.

IMPACT TESTING

General

12. Once it had been decided that cold solid projectiles could be used to determine impact properties, we examined the possibilities of some kind of test machine which would eject the projectile at all speeds from zero to 1,000 feet per second. Obviously the construction of such a machine would have been no easy matter and so, desirable as we still think it as a matter of pure research, we decided that we must use a quicker and perhaps more practical approach.

We had decided that the known velocity of 20,000 feet per minute or 333.3 feet per second must be met, which meant in practice that the selected materials should be capable of withstanding a projectile with a speed range from 330 to 400 feet per second. We concluded therefore that the proposed test rig must cover this range.

13. Major Reid had used a steel cube weighing about 1 gram and so we decided to use a projectile of the same weight in order to have comparable results. We thought that $\frac{1}{4}$ inch diameter steel ball-bearings would be convenient projectiles because they weigh about 1 gram, they are easily obtained and they are made to known tolerances of hardness, shape and size.

14. We decided, too, that the proposed rig should be so constructed that both single lenses and full goggles or spectacles could be tested in it. The testing of single lenses would give information on the impact properties of the materials and the testing of completed goggles would indicate the final impact values which could be withstood. This represented two distinct phases of the work and we proceeded first with the testing of lenses so as to find suitable material which could be incorporated in finished goggles.

Proposed Methods of Testing

15. We considered several methods of testing before reaching any final decision. The simplest method would have been a drop test. It was obvious enough that projectile velocities of the order of 400 feet per second could not have been obtained from any reasonable height, but we did consider the possibility of dropping a much heavier projectile from some practicable height. Had we done so, we should have used a projectile of such weight and dropped it from such a height that it bore the same momentum as the $\frac{1}{4}$ inch diameter ball-bearing at a speed of 400 feet per second. The effects of impact are, however, determined to an appreciable extent, by the time over which the energy of the projectile has to be absorbed. The heavier projectile at slower speeds could not, therefore, be expected to reproduce the effects of the lighter one at much higher speeds and so this suggestion was discarded.

16. We then contemplated the use of some compressed air operated mechanism which might be so designed that it would cover the whole velocity range from zero to 1,000 feet per second. We found no such easily available commercial apparatus which could be adapted to our purpose and we pursued this line of thought no further once we had decided that we could, fairly quickly, explore the velocity range in which we were immediately interested.

17. We discussed the use of cartridges with a suitable explosive substance as propellant. The speed range was somewhat low for normal ballistic purposes but the method was discarded chiefly because of the costly equipment involved (chronometers etc.) and the difficulty of the experimental method with the consequent necessity for a skilled operator with each test rig. Major Reid had had the services of such a specialist but we were looking for a test which could be easily reproduced by large numbers of people if necessary.

18. We also examined two mechanical methods of testing. The first idea was to drop a weight over a known distance, the weight being suspended from a chain wrapped round the rim of a wheel, so that as the weight fell the wheel rotated. If the wheel were mounted on a shaft which also carried a striker arm, the peripheral velocity of the wheel could be calculated from the height through which the weight fell, and the peripheral velocity of the tip of the striker arm could also be calculated from the ratio of the wheel radius to the length of the arm. If the tip of the striker arm were then to strike a ball-bearing it would be swept away at the speed of the tip itself. This projectile speed could be altered by

adjusting the height through which the weight fell and the ratio of the radius of the wheel to the length of the arm, or by providing linkages of varying lengths.

19. The second mechanical proposal was to run a fly wheel on a hollow shaft inside a close fitting case provided with a single $\frac{1}{4}$ inch diameter opening in the periphery. The fly wheel would be drilled with a $\frac{1}{4}$ inch diameter duct passing radially from the surface to the hollow shaft. Ball-bearings could then be rolled down the hollow shaft to the centre of the fly wheel from where they would be thrown centrifugally along the radial duct to leave the edge of the outer casing through the single $\frac{1}{4}$ inch diameter hole. The velocity of the projectile could be varied by varying the speed of the fly wheel.

20. There could be no doubt that these methods would present many practical difficulties and so, finally, we passed them over in favour of a simpler method which, whilst it would not give information over the whole range of speed, would at any rate give us information on the specific speed range we had selected. We were informed that an air rifle could be modified to give mean projectile velocities within the range 300–500 feet per second when using a $\frac{1}{4}$ inch diameter ball-bearing as projectile. We decided, therefore, that we should proceed to the construction of a suitable rig to take this weapon in order to procure further information quickly.

Air Rifle Test Rig

21. A prototype weapon was produced by B.S.A. (Guns) Limited. The barrel and the loading plug were opened up to take a $\frac{1}{4}$ inch diameter ball-bearing and the mechanism was modified so that the weapon imparted to the projectile a mean velocity within the required range of 330–400 feet per second. Figure 14 shows the complete rig with the weapon in position and the guard over the specimen holder. Figure 15 shows the rig without weapon and with the guard removed. Figure 16 is a line drawing of the assembly and Figure 17 a detailed drawing.

22. The aluminium base plate, which is thirty-four inches long and eight inches wide, carries at its left-hand end a micro-adjustable vee block with a fixed vee block at a distance of $14\frac{1}{2}$ inches centres. The weapon rests on these vee blocks with the muzzle inserted into the centre opening provided in the left-hand end of the mild steel muzzle locating cylinder. The rifle can be aimed at any part of the specimen by adjusting the micro vee block and rotating the specimen (Figures 14 and 15). The inside surface of the left-hand end of the locating cylinder is protected by means of a rubber sleeve (Figure 16) and the end of the rifle muzzle should also be protected from shots which ricochet from unbroken lenses. This protection of the muzzle end is of great importance as the impact of spent shot thereon is sufficient to burr it over, so reducing its exit diameter. The first weapon that was used had to be reground owing to damage sustained in this way.

23. The aluminium specimen holder is lined with a mild steel bush with an internal thread (Figure 16). When a specimen has been placed in the holder it is held at the back by a clamping sleeve (Figure 17) which is retained in position by the mild steel locking tube which is screwed up behind the head (Figure 16). Early tests were done with the specimens held between the aluminium faces of the specimen holder and the clamping sleeve, the locking tube being screwed by hand until the specimen was just held. This system was sufficient for preliminary work but for a standard rig the specimen should be held between gaskets and the

locking tube should be tightened by means of a torque spanner operating on a nut affixed to the closed end of the tube.

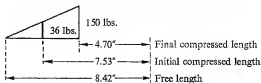
24. The locking tube with its closed end is also used to absorb the spent ball if the specimen should fail. For this reason it is packed with cotton wool but a layer of plasticine is placed over the wool at a distance of $\frac{1}{4}$ of an inch behind the specimen (Figure 16). Shots which have penetrated the specimen will, therefore, embed themselves in the plasticine.

25. Shots which failed to penetrate the specimen rebound violently and so a guard is fitted over the specimen holder, being large enough to cover also part of the rifle muzzle locating cylinder and so close the gap between locating cylinder and specimen holder (Figures 14, 16 and 17).

Calibration

26. All specimens were cut to 50 mm. diameter circles. The projectiles were standard 0.25" diameter ball-bearings, hardened to 63/65 Rockwell "C", and guaranteed to within 0.0001" of nominal size and sphericity. The weapon was a prototype modified B.S.A. "Airsporter" of the following specification:

1. Barrel bore H 0.2503".
L 0.2501".
2. Barrel loading plug—bore size 0.260".
3. Mainspring. Standard spring set to reduced free length.



4. Maximum fibre stress (mainspring) 158,500 lbs./in.²
5. Method of recording velocities. Works "Holden" chronograph.
6. Suggested limits of chronograph accuracy $\pm 2\%$.
7. Mean observed velocity (over 5 yards) 390.4 ft. per second.
8. Projectile. Standard $\frac{1}{4}$ " spherical steel ball-bearing.
9. Weight of projectile 16.1 grains (1.043 grammes).
10. Mean propulsion force 93 lbs.
11. Mean propulsion energy 22 ft./lb.
12. Muzzle energy of projectile 5.44 ft./lb.
13. Mechanical efficiency of weapon 24.7%.

Test Procedures

27. We have done all our tests at temperatures between 65°F. and 75°F., the rig and the specimens having first been allowed sufficient time to reach the ambient temperature of the room in which they were tested. We were informed that the properties of plastic materials would vary somewhat with temperature and that the variation itself would be different for different materials. It has, of

course, not been possible in the time available to test all the conceivable combinations of the various materials that might be used although we hope that the whole range will be explored in due course and when this is done the temperature at which the tests are made may be of some importance.

28. We were informed that the velocity of the projectile would remain constant over a large number of shots. We have, however, had the velocity checked at different stages of the work and we have also kept a record of the number of shots fired in an attempt to determine at what point the velocity begins to fall if this in fact occurs. So far the initial velocity has been maintained but this is obviously an important matter in continuous testing.

29. The plasticine must be used in front of the cotton wool in the sleeve locking tube and care must be taken to ensure that there are no ball-bearings in this plasticine when a lens is tested. This is important because we have found that some thin specimens which had been penetrated by the shot showed only a very small hole on subsequent examination. For instance, one specimen was indented and at the base of the indentation there was a hole no more than $\frac{1}{16}$ " in diameter. On first examination we thought that the specimen had withstood the missile, merely being indented and cracked at the base of the indentation by the impact. When the sleeve locking tube was removed however the missile was found in the plasticine. Clearly it had penetrated the specimen and as a $\frac{1}{4}$ " diameter ball had left a hole no larger than $\frac{1}{16}$ " in diameter, the aperture must have opened up for the passage of the projectile and closed again behind it. It is therefore essential that the plasticine be kept free of spent ball-bearings so that if one is found therein after a test it can be stated with confidence that the ball in question had penetrated the specimen whatever the final state of the specimen might be.

30. The guard should be placed in position for every shot because projectiles rebound with some violence when the specimens withstand the blow.

31. We have used two test procedures. In the first instance, we submitted each specimen to one blow only at the centre. We repeated the test a number of times so that the materials could be placed in an order of merit, e.g. those which always failed, those which sometimes failed and those which never failed. Originally, we thought that we might have to accept lenses which failed no more than a certain percentage of the tests but later we found lenses which never failed on the first test.

32. The second test procedure was used in order to test to destruction. Lenses which were known to be strong enough to withstand the first test procedure were placed into the testing rig and successive projectiles were fired at the centre of each of these lenses until it was cracked, broken or penetrated—the lens being examined between each shot. It was appreciated that each shot would stress the material of the specimen so that no two of the shots would be fired at the material in the same state of internal stress. Nevertheless, we thought that the total number of shots would give some indication of ultimate strength. Certainly this procedure gave conditions much more severe than would occur in practice when it is hardly conceivable that a goggle lens would be struck even twice on precisely the same spot.

Results of Impact Tests

33. The impact results are given in Tables I to XXVI. It will be seen that all glass specimens, toughened and laminated, failed completely, being shattered and penetrated by the first shot (Table I).

34. The 3 mm. wired acetate specimen also failed not because it was penetrated but because it bent and cracked and the back surface which would have been adjacent to the wearer's eye threw off a heavy shower of splinters. The 4 mm. wired laminated acetate specimen withstood the first shot and cracked without splintering on the second shot (Table II).

35. One of the three Triplex laminated plastic specimens was penetrated and only the thickest one was successful. This one cracked, but the two thinner ones threw off splinters from the back surface—splinters which might well go into the eye of the wearer (Table III).

36. Single plastic lenses failed up to and including 3 mm. thick. Some of the 3 mm. lenses withstood one blow but some were penetrated by the first shot. It appears that some plastics are strong enough if they are 4 or 6 mm. thick, but others still fail. The results suggest that overall thickness is no real criterion because thinner double lenses were superior (Tables IV and V).

37. We tested double lenses with varying thicknesses of different plastics. These lenses consisted simply of two layers of plastic material placed together with the thinner layer receiving the blow. The two layers were not stuck together in any way and so we have called them "double lenses" to distinguish them from true laminated lenses in which the layers are held together by an adhesive. The results (Tables VI to XXVI) show that the following double lenses were satisfactory:—

- (a) 0.050" Celastoid + 0.080" Celastoid
- (b) 0.060" Celastoid + 0.080" Celastoid
- (c) 0.040" Vybak + 0.060" Vybak
- (d) 0.060" Vybak + 0.060" Vybak
- (e) 0.040" Celastoid + 0.060" Vybak

We wish to emphasise that the materials listed above may not be the only materials which are satisfactory for this purpose. There may be other materials which we have not tested, or of which we are not aware, which may give equal or better results.

BURNING TESTS

Equipment

38. Hot solid projectiles may be embedded in plastic lenses which they have failed to penetrate, and so it is necessary to determine the resistance of the plastic specimens to the heat that might be applied in this way. In our earlier tests on the effects of heat we laid a hot $\frac{1}{2}$ inch diameter ball-bearing (at 900°C) on the top surface of a horizontal lens and noted the time taken for the ball to penetrate. In order that the hot ball should not roll about on the lens, we counter-sunk the centre. This virtually reduced the thickness of the lens, and we thought that this was undesirable. In consequence we have now constructed the equipment shown in Figure 18.

The hot ball is placed in the funnel and centres itself at once on the lens. The funnel is immediately lifted off, so that it does not cool the ball. If the ball penetrates the lens, the time of penetration is noted.

Results

39. We tested only certain lenses, selected from the impact tests, and the results are given in Table XXVII. When the materials mentioned in paragraph 37 were tested some smoke was produced, although none of the specimens took fire and no flame resulted from any test.

All the materials were penetrated when tested as a single layer of about 0.060 inch thick, the Celastoid taking 10 seconds and the Vybak 1 minute 14 seconds. The best impact results, however, had come from double lenses, and so we tested these and in no case did the hot ball penetrate.

NEEDLE TESTS

40. Some tests were done on the machine described in our first report, and the results are given in Tables XXVIII and XXIX.

GOGGLE TESTING

41. Now that some suitable materials have been found, complete goggles must be tested on an impact testing rig which we are now making for this purpose.

CONCLUSIONS

42. (1) The conclusions reached in our First Report were confirmed and amplified.
- (2) Impact tests can be done with cold solid projectiles so long as the effects of heat are estimated by means of other tests.
- (3) Impact testing should be done at a velocity at least as high as 20,000 feet per minute.
- (4) All toughened and laminated glass lenses completely failed the impact test. They were also cracked and broken when tested against molten projectiles. They are therefore unsuitable for use in foundries.
- (5) Certain laminated plastic lenses and certain double plastic lenses withstood the impact test and were also satisfactory against heat tests. Other types of plastic lenses may well be developed in the future but we have no doubt now that existing and easily available plastic materials will give complete protection against the fairly severe tests that we have applied. We take the view therefore that lenses of these types are suitable for use in foundries.
- (6) These plastic lenses will have to be securely mounted in suitable frames and the testing of complete goggles and spectacles is therefore the next stage of our work.
- (7) The ophthalmological properties of the selected lenses must now be investigated and work has already started on this aspect of the matter.

ACKNOWLEDGMENTS

43. We are greatly indebted to Mr. Livermore of the Midland Motor Cylinder Co. Ltd., for facilities for practical work and to the Directors of B.S.A. (Guns) Ltd., for the prototype air rifle without which none of the work could have been done. We are also under obligation to Triplex Safety Glass Co. Ltd., Imperial Chemical Industries Ltd., B.X. Plastics Ltd., British Celanese Ltd., Bakelite Ltd. and Parmalee (G.B.) Ltd., for specimens.

(Signed) A. W. BUSHELL
W. B. LAWRIE

TABLE I

Impact Tests on Glass

No.	Material	Remarks
1	Toughened Glass.	One centre shot penetrated and completely shattered and disintegrated lens.
2	Laminated Toughened Glass.	One centre shot penetrated and shattered lens.

TABLE II

Impact Tests on Wire Laminated Acetate

No.	Thickness	Remarks
3	3 mm.	One centre shot bent and cracked the specimen, the back surface being badly splintered.
4	4 mm.	Specimen cracked on second consecutive centre shot.

TABLE III

Impact Tests on Perspex Laminated Lenses

No.	Material	Remarks
5	Three $\frac{1}{16}$ " Perspex with two 0.060" vinyl interlayers.	One centre shot cracked. No splinters from back face.
6	Two $\frac{1}{16}$ " Perspex with one 0.060" vinyl interlayer.	One centre shot splintered both faces—back face badly splintered.
7	Two $\frac{1}{16}$ " Perspex with one 0.020" vinyl interlayer.	Penetrated and badly splintered by one centre shot.

TABLE IV

Impact Tests on Celastoid

No.	Thickness	Remarks
8	0.020"	One centre shot penetrated.
9	0.030"	One centre shot penetrated.
10	0.040"	One centre shot penetrated.
11	0.050"	One centre shot penetrated.
12	0.060"	One centre shot penetrated.
13	0.080"	One centre shot penetrated.
14	3 mm.	One centre shot penetrated.
15	4 mm.	Cracked at 7th shot. 1st and 2nd shots in centre, 3rd, 4th, 5th and 6th shots at periphery and 7th shot in centre.
16	6 mm.	Cracked on 10th consecutive centre shot. Six further shots placed in centre (i.e. total 16)—lens not broken out of ring—no splinters from back surface.
17	3 lenses by 0.030" each	One centre shot penetrated and shattered this three layer lens.
18	4 lenses by 0.010" each	One centre shot. Four layer lens not penetrated, but all layers broken and one piece broken off back layer.
19	0.020" + 3 mm.	One centre shot. Front layer (0.020") cracked, no penetration, piece broken away. Back lens slightly marked—virtually undamaged.
20	0.015" + 3 mm.	One centre shot—no damage. Second centre shot cracked both. No splinters from back.

TABLE V

Impact Tests on Celastoid

No.	Thickness	Remarks
21	0.040"	Broken and penetrated by one centre shot.
22	0.050"	Broken and penetrated by one centre shot.
23	0.060"	Penetrated by one centre shot.
24	0.080"	No damage by one centre shot.
25	0.080"	No damage by one centre shot. A 0.010" lens then put in front and second shot fired. The 0.010" lens cracked but not penetrated and no damage to 0.080" lens.
26	0.080"	Penetrated by one centre shot.
27	0.080"	Penetrated by one centre shot.
28	0.080"	No damage by one centre shot.
29	0.080"	Shattered by second centre shot.
30	0.080"	Shattered by second centre shot.
31	3 mm.	Shattered by one centre shot.
32	3 mm.	Penetrated by one centre shot.
33	3 mm.	Cracked but not penetrated by one centre shot.
34	3 mm.	No damage by one centre shot.
35	3 mm.	Cracked but not penetrated by one centre shot.
36	4 mm.	Cracked but not splintered by one centre shot.
37	4 mm.	Cracked but not splintered by one centre shot.
38	4 mm.	Cracked but not splintered by 5th consecutive centre shot.
39	4 mm.	Cracked but not splintered by 2nd consecutive centre shot.
40	4 mm.	Cracked but not splintered by 5th consecutive centre shot.
41	4 mm.	Cracked but not splintered by 1st centre shot.
42	6 mm.	Cracked but not splintered by 11th consecutive centre shot.
43	0.030" + 0.030"	Penetrated and both lenses broken by one centre shot.
44	0.030" + 0.030" + 0.030"	Front lens cracked by one centre shot.

TABLE VI

Impact Tests on Celastoid		
No.	Thickness	Remarks
45	0.010" + 0.040"	Penetrated by one centre shot.
46	0.015" + 0.040"	Penetrated by one centre shot.
47	0.020" + 0.040"	Penetrated by one centre shot.
48	0.030" + 0.040"	Front lens cracked by one centre shot.
49	0.040" + 0.040"	No damage by one centre shot.
50	0.040" + 0.040"	Front lens cracked by one centre shot.
51	0.040" + 0.040"	No damage by one centre shot. Penetrated by second centre shot.

TABLE VII

Impact Tests on Celastoid		
No.	Thickness	Remarks
52	0.010" + 0.050"	Penetrated by one centre shot.
53	0.015" + 0.050"	Penetrated by one centre shot.
54	0.020" + 0.050"	Penetrated by one centre shot.
55	0.030" + 0.050"	No damage by one centre shot.
56	0.030" + 0.050"	Penetrated by one centre shot.
57	0.040" + 0.050"	Front lens cracked by one centre shot.
58	0.040" + 0.050"	No damage by one centre shot.
59	0.050" + 0.050"	No damage by one centre shot.
60	0.050" + 0.050"	Front lens cracked by 3rd centre shot.
61	0.050" + 0.050"	Front lens cracked by one centre shot.
62	0.050" + 0.050"	Front lens cracked by 4th centre shot.

TABLE VIII

Impact Tests on Celastoid

No.	Thickness	Remarks
63	0.010" + 0.060"	Penetrated by one centre shot.
64	0.015" + 0.060"	Penetrated by one centre shot.
65	0.020" + 0.060"	Penetrated by one centre shot.
66	0.030" + 0.060"	Penetrated by one centre shot.
67	0.040" + 0.060"	No damage by one centre shot.
68	0.040" + 0.060"	Penetrated and shattered by one centre shot.
69	0.040" + 0.060"	Front lens cracked by 2nd centre shot.
70	0.040" + 0.060"	Penetrated and broken by one centre shot.
71	0.050" + 0.060"	No damage by one centre shot.
72	0.050" + 0.060"	Penetrated and shattered by 3rd centre shot.
73	0.050" + 0.060"	Front lens intact but large piece broken out of centre of back lens by one centre shot.
74	0.050" + 0.060"	Penetrated and broken by 2nd centre shot.
75	0.060" + 0.060"	No damage by one centre shot.
76	0.060" + 0.060"	Front lens cracked by 3rd centre shot.
77	0.060" + 0.060"	Front lens cracked by one centre shot.

TABLE IX

Impact Tests on Celastoid

No.	Thickness	Remarks
78	0.010" + 0.080"	Penetrated by one centre shot.
79	0.015" + 0.080"	Front lens cracked by one centre shot.
80	0.020" + 0.080"	No damage by one centre shot.
81	0.030" + 0.080"	No damage by one centre shot.
82	0.040" + 0.080"	No damage by one centre shot.
83	0.050" + 0.080"	No damage by one centre shot.
84	0.060" + 0.080"	No damage by one centre shot.
85	0.080" + 0.080"	No damage by one centre shot.

TABLE X

Impact Tests on Celastoid

A survey of Test Nos. 8 to 85 suggested that a double Celastoid lens, with the back one 0.080" thick, would give good results and so following tests were then done.

No.	Thickness	Remarks
86	0.020" + 0.080"	Front lens cracked by one centre shot. Front lens replaced by another 0.020". Back lens used again for next test (No. 87).
87	0.020" + 0.080"	Front lens cracked by one centre shot. Front lens replaced by another 0.020". Back lens used again for next test (No. 88).
88	0.020" + 0.080"	Front lens cracked by one centre shot. Front lens replaced by another 0.020". Back lens used again for next test (No. 89).
89	0.020" + 0.080"	Penetrated and both lenses shattered by one centre shot.

That is, the same 0.080" lens was used with four 0.020" lenses and broken at the fourth centre shot.

These tests (Nos. 86-89) were repeated with identical results.

TABLE XI

Impact Tests on Celastoid

Repeat of Table X using a 0.030" lens with one 0.080" lens

No.	Thickness	Remarks
94	0.030" + 0.080"	No damage by one centre shot. Front lens replaced by another 0.030". Back lens used again for next test (No. 95).
95	0.030" + 0.080"	Penetrated by one centre shot.

That is, the 0.080" lens failed at the second centre shot.

TABLE XII

Impact Tests on Celastoid

Repeat of Table XI

No.	Thickness	Remarks
96	0.030" + 0.080"	No damage by one centre shot. Front lens replaced by another 0.030". Back lens used again for next test.
97	0.030" + 0.080"	No damage by one centre shot. Front lens replaced by another 0.030". Back lens used again for next test.
98	0.030" + 0.080"	No damage by one centre shot. Front lens replaced by another 0.030". Back lens used again for next test.
99	0.030" + 0.080"	No damage by one centre shot. Front lens replaced by another 0.030". Back lens used again for next test.

That is, the same 0.080" lens was used with four 0.030" lenses and remained undamaged.

TABLE XIII

Impact Tests on Celastoid

Repeat of Table XII

No.	Thickness	Remarks
100	0.030" + 0.080"	No damage by one centre shot. Front lens replaced by another 0.030". Back lens used again for next test.
101	0.030" + 0.080"	Penetrated by one centre shot.

That is, the same 0.080" lens was used with two 0.030" lenses and failed at the second centre shot.

TABLE XIV

Impact Tests on Celastoid

Repeat of Tables X, XI, XII and XIII using 0.040" lenses with one 0.080" lens

No.	Thickness	Remarks
102	0.040" + 0.080"	No damage by one centre shot. Front lens replaced by another 0.040". Back lens used again for next test.
103	0.040" + 0.080"	No damage by one centre shot. Front lens replaced by another 0.040". Back lens used again for next test.
104	0.040" + 0.080"	No damage by one centre shot. Front lens replaced by another 0.040". Back lens used again for next test.
105	0.040" + 0.080"	No damage by one centre shot. Front lens replaced by another 0.040". Back lens used again for next test.
106	0.040" + 0.080"	No damage by one centre shot. Front lens replaced by another 0.040". Back lens used again for next test.
107	0.040" + 0.080"	The 0.040" front lens was not again replaced. This double lens was penetrated at third centre shot.

That is, the same 0.080" lens was used with six 0.040" lenses. Penetration occurred on the third centre shot on the sixth 0.040" lens at the eighth shot against the 0.080" lens.

TABLE XV

Impact Tests on Celastoid

Repeat of Tables X, XI, XII, XIII and XIV using 0.050" lenses with one 0.080" lens

No.	Thickness	Remarks
110	0.050" + 0.080"	No damage by one centre shot. Front lens replaced by another 0.050". Back lens used again for next test.
111	0.050" + 0.080"	No damage by one centre shot. Front lens replaced by another 0.050". Back lens used again for next test.
112	0.050" + 0.080"	No damage by one centre shot. Front lens replaced by another 0.050". Back lens used again for next test.
113	0.050" + 0.080"	No damage by one centre shot. Front lens replaced by another 0.050". Back lens used again for next test.
114	0.050" + 0.080"	No damage by one centre shot. Front lens replaced by another 0.050". Back lens used again for next test.
115	0.050" + 0.080"	The 0.050" front lens was not replaced again. This double lens was cracked at the seventh centre shot.

That is, the same 0.080" lens was used with six 0.050" lenses. The lenses cracked on the seventh centre shot on the sixth 0.050" lens which was the twelfth shot on the 0.080" lens.

TABLE XVI

Impact Tests on Celastoid		
No.	Thickness	Remarks
122	0.030" + 0.060"	1st shot—front lens cracked—replaced.
123	0.030" + 0.060"	2nd shot—no damage—lens tested again.
124	0.030" + 0.060"	3rd shot—penetrated and both lenses broken.

TABLE XVII

Impact Tests on Celastoid		
No.	Thickness	Remarks
125	0.040" + 0.060"	1st shot—no damage.
126	0.040" + 0.060"	2nd shot—no damage.
127	0.040" + 0.060"	3rd shot—no damage.
128	0.040" + 0.060"	4th shot—penetrated and both lenses broken.
129	0.040" + 0.060"	1st shot—no damage.
130	0.040" + 0.060"	2nd shot—front lens cracked—replaced.
131	0.040" + 0.060"	3rd shot—front lens cracked—replaced.
132	0.040" + 0.060"	4th shot—no damage.
133	0.040" + 0.060"	5th shot—no damage.
134	0.040" + 0.060"	6th shot—no damage.
135	0.040" + 0.060"	7th shot—front lens undamaged. A piece broke away from middle of back lens.

TABLE XVIII

Impact Tests on Celastoid		
No.	Thickness	Remarks
136	0.030" + 0.080"	1st shot—no damage.
137	0.030" + 0.080"	2nd shot—no damage.
138	0.030" + 0.080"	3rd shot—front lens cracked—replaced.
139	0.030" + 0.080"	4th shot—no damage.
140	0.030" + 0.080"	5th shot—no damage.
141	0.030" + 0.080"	6th shot—front lens cracked. A piece broke away from middle of back lens.
142	0.030" + 0.080"	1st shot—no damage.
143	0.030" + 0.080"	2nd shot—no damage.
144	0.030" + 0.080"	3rd shot—front lens cracked—replaced.
145	0.030" + 0.080"	4th shot—no damage.
146	0.030" + 0.080"	5th shot—no damage.
147	0.030" + 0.080"	6th shot—penetrated and both lenses broken.

TABLE XIX

Impact Tests on Celastoid		
No.	Thickness	Remarks
148	0.040" + 0.080"	1st shot—no damage.
149	0.040" + 0.080"	2nd shot—no damage.
150	0.040" + 0.080"	3rd shot—penetrated and both lenses broken.
151	0.040" + 0.080"	1st shot—no damage.
152	0.040" + 0.080"	2nd shot—no damage.
153	0.040" + 0.080"	3rd shot—no damage.
154	0.040" + 0.080"	4th shot—front lens undamaged. A large piece broke away from middle of back lens.

TABLE XX

Impact Tests on Celastoid		
No.	Thickness	Remarks
155	0.050" + 0.080"	1st shot—front lens broken—replaced.
156	0.050" + 0.080"	2nd shot—front lens cracked—replaced.
157	0.050" + 0.080"	3rd shot—penetrated and both lenses broken.
158	0.050" + 0.080"	1st shot—no damage.
159	0.050" + 0.080"	2nd shot—front lens cracked—replaced.
160	0.050" + 0.080"	3rd shot—front lens cracked—replaced.
161	0.050" + 0.080"	4th shot—front lens cracked—replaced.
162	0.050" + 0.080"	5th shot—front lens cracked—replaced.
163	0.050" + 0.080"	6th shot—front lens broken—replaced.
164	0.050" + 0.080"	7th shot—penetrated and both lenses broken.
165	0.050" + 0.080"	1st shot—no damage.
166	0.050" + 0.080"	2nd shot—no damage.
167	0.050" + 0.080"	3rd shot—no damage.
168	0.050" + 0.080"	4th shot—no damage.
169	0.050" + 0.080"	5th shot—no damage.
170	0.050" + 0.080"	6th shot—no damage.
171	0.050" + 0.080"	7th shot—no damage.
172	0.050" + 0.080"	8th shot—no damage.
173	0.050" + 0.080"	9th shot—no damage.
174	0.050" + 0.080"	10th shot—no damage.
175	0.050" + 0.080"	11th shot—penetrated and both lenses broken.

TABLE XXI

Impact Tests on Celastoid

No.	Thickness	Remarks
176	0.060" + 0.080"	1st shot—no damage.
177	0.060" + 0.080"	2nd shot—no damage.
178	0.060" + 0.080"	3rd shot—no damage.
179	0.060" + 0.080"	4th shot—no damage.
180	0.060" + 0.080"	5th shot—no damage.
181	0.060" + 0.080"	6th shot—no damage.
182	0.060" + 0.080"	7th shot—no damage.
183	0.060" + 0.080"	8th shot—front lens undamaged. A piece broke away from middle of back lens.
184	0.060" + 0.080"	1st shot—front lens cracked—replaced.
185	0.060" + 0.080"	2nd shot—no damage.
186	0.060" + 0.080"	3rd shot—no damage.
187	0.060" + 0.080"	4th shot—no damage.
188	0.060" + 0.080"	5th shot—no damage.
189	0.060" + 0.080"	6th shot—no damage.
190	0.060" + 0.080"	7th shot—no damage.
191	0.060" + 0.080"	8th shot—no damage.
192	0.060" + 0.080"	9th shot—front lens cracked. A piece broke away from middle of back lens.
193	0.060" + 0.080"	1st shot—no damage.
194	0.060" + 0.080"	2nd shot—no damage.
195	0.060" + 0.080"	3rd shot—no damage.
196	0.060" + 0.080"	4th shot—no damage.
197	0.060" + 0.080"	5th shot—front lens undamaged. A piece broke away from centre of lens.

TABLE XXII

Impact Tests on Celastoid		
No.	Thickness	Remarks
198	0.030" $\pm$ 3 mm.	1st shot—no damage.
199	0.030" $\pm$ 3 mm.	2nd shot—no damage.
200	0.030" $\pm$ 3 mm.	3rd shot—both cracked (neither splintered nor penetrated).

TABLE XXIII

Impact Tests on Celastoid		
No.	Thickness	Remarks
201	0.30" $\pm$ 3 mm.	1st shot—no damage.
202	0.30" $\pm$ 3 mm.	2nd shot—no damage.
203	0.30" $\pm$ 3 mm.	3rd shot—no damage.
204	0.30" $\pm$ 3 mm.	4th shot—front lens undamaged. A piece broke away from middle of back lens.

TABLE XXIV

Impact Tests on Vybak—Test Temperature 74°F.

No.	Thickness	Remarks
205	0.020"	Penetrated by first shot—ball embedded in plasticine.
206	0.040"	Penetrated by first shot—ball embedded in plasticine.
207	0.060"	Penetrated by first shot, but momentum of ball spent so that it was not embedded in plasticine but fell loosely in ball trap.
208	0.020" + 0.020"	Penetrated by first shot—ball embedded in plasticine.
209	0.020" + 0.040"	Penetrated by first shot, but momentum of ball spent so that it was not embedded in plasticine but fell loosely in ball trap.
210	0.020" + 0.060"	No penetration by one shot—both lenses indented where struck by ball.
211	0.020" + 0.060"	Penetrated by second shot and ball embedded in plasticine.
212	0.040" + 0.040"	No penetration by one shot—both lenses indented where struck by ball.
213	0.040" + 0.040"	Penetrated by second shot and ball embedded in plasticine.
214	0.040" + 0.060"	No penetration by one shot, front lens indented, no visible damage to back lens.
215	0.040" + 0.060"	Ball penetrated front (0.040") lens at third shot, and lodged therein without penetrating back lens (0.060").
216	0.060" + 0.060"	No penetration by one shot. Slight indentation front lens. No visible damage to back lens.
217	0.060" + 0.060"	Penetrated at seventh shot and ball embedded in plasticine.

TABLE XXV

Impact Tests on Perspex

No.	Thickness	Remarks
18	0.125"	Lens shattered by one shot.
	0.125" + 0.125"	Lens shattered by one shot.
	0.040" + 0.040"	Penetrated by one shot.
	0.040" + 0.125"	Penetrated by one shot.
	0.040" + 0.094"	Penetrated by one shot.
223	0.040" + 0.0625"	Penetrated by one shot.
224	0.040" + 0.040" + 0.040"	Penetrated by one shot.

TABLE XXVI

Impact on Mixed Lenses

No.	Thickness	Remarks
225	0.040" Perspex + 0.020" Vybak + 0.040" Perspex	Penetrated by one shot.
226	0.040" Perspex + 0.060" Vybak	Ball rebounded after breaking front lens (Perspex). Fragments of Perspex embedded in Vybak. Vybak not penetrated.
227	0.040" Celastoid + 0.060" Vybak	No penetration by one shot. Indentation on Celastoid. Vybak marked.

TABLE XXVII

Burning Tests

No.	Material and Thickness	Remarks
1	Celastoid 0.060"	Smoke. Ball penetrated 10 secs.
2	Vybak 0.060"	Little smoke. Ball penetrated 1 min. 14 secs.
3	Perspex 0.0625"	Very little smoke. Ball penetrated 21.7 secs.
4	Celastoid 0.040" + Vybak 0.060"	Smoke—no penetration.
5	Perspex 0.040" + Vybak 0.060"	Little smoke. No penetration.
6	Vybak 0.040" + Vybak 0.060"	Little smoke. No penetration.
7	Vybak 0.060" + Vybak 0.060"	Little smoke. No penetration.
8	Celastoid 0.040" + Celastoid 0.080"	Ball penetrated 17.1 secs.
9	Celastoid 0.050" + Celastoid 0.080"	Ball virtually penetrated but did not fall.
10	Celastoid 0.060" + Celastoid 0.080"	Ball penetrated 41.6 secs.
11	Vybak 0.040"	Ball penetrated 19.2 secs. Prolific smoke.
12	Vybak 0.060"	Ball virtually penetrated 1 min. 40 secs. but did not fall.

TABLE XXVIII

Needle Tests on Celastoid

Applies to Satisfactory Combination of Lenses from High Velocity Tests on Celastoid

1 <i>Maximum spring tension:</i> $0.020'' \pm 0.080''$	<i>0.010'' needle clearance.</i> Slight cracks appeared on the 0.080'' back lens at the ninth blow. The cracks had extended to $\frac{1}{2}$ inch in length at the fifteenth blow. There was no further extension of the cracks even after twenty-one blows.
2 <i>Maximum spring tension:</i> $0.020'' \pm 0.080''$	<i>No needle clearance.</i> Slight cracks appeared at the second blow. The cracks extended at the third blow. The cracks extended further at the fourth blow. There was no further extension of the cracks even after twenty-one blows. <i>Note:</i> Examination of the front 0.020'' lens after removal from the machine revealed that the needle had made a centre hole in it but the material had not cracked.

TABLE XXIX

Needle Tests on Colastoid

No.	<i>Maximum spring tension</i>	<i>0.010" needle clearance</i>
3	$0.030'' + 0.080''$	Slight cracks appeared in the front lens at the seventh blow. These cracks extended progressively to $\frac{1}{4}''$ in length at the seventeenth blow. There was no further extension of the cracks when twenty blows had been struck.
Upon removal of the specimens it was found that there was a needle hole in the front lens. The back lens had needle indentation and two cracks, each $\frac{1}{4}''$ in length.		
4	$0.040'' + 0.080''$	Slight cracks appeared in the front lens at the eighth blow. These cracks extended progressively to $\frac{1}{4}''$ in length by the eleventh blow. There was no further damage after twenty blows.
Upon removal of the specimens it was found that there was a needle hole in the front lens. There was needle indentation in the back lens.		
5	$0.050'' + 0.080''$	Slight cracks appeared in the front lens at the sixth blow. These cracks were extended to $\frac{1}{4}''$ in length at the tenth blow, and to $\frac{1}{2}''$ at the twentieth blow.
Upon removal of the specimens it was found that there was a needle hole in the front lens. There was needle indentation in the back lens.		
6	$0.060'' + 0.080''$	A slight crack appeared in the front lens at the first blow. This crack extended very little at the seventh blow. There was no further extension after twenty blows.
Upon removal of the specimens it was found that there was a needle hole in the front lens, but the back lens was only very slightly marked by the needle.		
	<i>Maximum spring tension</i>	<i>No needle clearance</i>
7	$0.030'' + 0.080''$	Upon removal of the specimens after 20 blows, it was found that there was a needle hole and minute cracks in the front lens. The back lens had needle indentation and one minute crack.
8	$0.040'' + 0.080''$	A minute crack appeared in the front lens at the eighth blow. A second crack appeared at the eleventh blow. A third crack appeared at the thirteenth blow. These cracks were each extended to $\frac{1}{2}''$ in length at the fifteenth blow. There was no further extension at twenty blows.
Upon removal of the specimens it was found that there was a needle hole in the front lens. The back lens had needle indentation and one minute crack.		
9	$0.050'' + 0.080''$	A crack $\frac{1}{2}''$ long appeared in the front lens at the first blow. A second $\frac{1}{2}''$ long crack appeared at the second blow. A third $\frac{1}{2}''$ long crack appeared at the sixth blow. The second crack was extended to $\frac{1}{2}''$ long and the third to $\frac{1}{2}''$ long at the twelfth blow. There was no further extension of these cracks at the twentieth blow.
Upon removal of the specimens it was found that there was a needle hole in the front lens. There was only slight needle indentation in the back lens.		

APPENDIX IV

CONTENTS

	Page
Third Interim Report of the Joint Advisory Committee on Foundry Goggles	104
Third Interim Report of the Sub-Committee of the Joint Advisory Committee on Foundry Goggles	105
Membership of the Sub-Committee of the Joint Advisory Committee on Foundry Goggles	105
INTRODUCTION	106
PRELIMINARY CONSIDERATIONS	107
THE IMPACT TEST RIG	108
IMPACT TESTS	109
IMPACT RESULTS	109
Spectacles	109
Face Screens	109
Goggles	110
HOT METAL TESTS	111
Molten Metal Test	111
Burning Test	111
MISCELLANEOUS TESTS	111
Impact Test on Nylon	111
Misting	111
CONCLUSIONS	112
ACKNOWLEDGMENTS	112
TABLES	113

**THIRD INTERIM REPORT OF THE
JOINT ADVISORY COMMITTEE ON FOUNDRY GOGGLES**

*Mr. T. W. McCullough, O.B.E.,
H.M. Chief Inspector of Factories.*

1. Our Technical Sub-Committee has now presented us with its Third Report after having:

- (a) devised a method of impact testing which is suitable for all kinds of eye protection and
- (b) developed one type of goggle which satisfies all the tests which have been described in the two previous and the present Interim Reports.

2. We have accepted this Report and decided to present it to you at once because it represents the completion of the third phase of the work of the Sub-Committee. You arranged for our First and Second Reports to be published in the Foundry Trade Journal and we hope that you will see your way to making similar arrangements for this Third Report in order that both the founding industry and the manufacturers of protective equipment for the eyes might be acquainted with the latest position. We hope that publicity of this kind will encourage the manufacturers of spectacles, goggles and face screens to proceed quickly with their own development work in order to provide a range of suitable equipment.

3. We have asked our Sub-Committee to proceed with further tests on the possible effects of temperature, age, moisture and anti-misting compounds on the lenses.

4. We are most grateful to the Technical Sub-Committee for the work that has been done.

(Signed) H. WOODS

J. HIGHAM

J. GARDNER

F. BULLOCK

G. CROWDEN

S. G. RAINSFORD

A. W. BUSHELL

W. B. LAWRIE

A. H. SULLY

H. C. WESTON

P. A. SWINDEN

H. V. SHELTON

**THIRD INTERIM REPORT OF THE SUB-COMMITTEE OF
THE JOINT ADVISORY COMMITTEE ON FOUNDRY GOGGLES**

Members of Sub-Committee

Mr. A. W. Bushell

Mr. W. B. Lawrie, M.B.E., M.Sc., F.R.M.S., A.I.M.

THIRD INTERIM REPORT OF THE SUB-COMMITTEE OF THE JOINT ADVISORY COMMITTEE ON FOUNDRY GOGGLES

Mr. H. Woods,

Chairman,

Joint Advisory Committee on Foundry Goggles

INTRODUCTION

1. We have now reached the end of the third stage of the work that was remitted to us by the Joint Advisory Committee on Foundry Goggles and so we are offering you a Third Report.

2. As a matter of convenience we quote here our previous conclusions. At the end of the first stage of our work we embodied our conclusions in paragraph 36 of our First Report which reads as follows:

" 36. The work has not yet been completed but sufficient has been done to lead us to certain definite conclusions.

- (a) Toughened glass should not be used as protection against molten metal nor should it be used to protect against flying particles in foundries.
- (b) Laminated glass is always broken by the molten metal and often broken by flying particles. In some cases splinters fly off from the surface of the laminated glass that would be adjacent to the wearer's eyes. It could not be said that laminated glass is useless but those of us who have seen the experimental work would not be comfortable again in using this material. We hold the view therefore that laminated glass should not be used in foundries.
- (c) Plastics are greatly superior to glass in resisting penetration by molten metal. Much more work needs to be done in order to determine the suitability of the various plastics for use as goggles but there can be no doubt that suitably designed plastic goggles are infinitely better than glass goggles in resisting penetration either by molten metal or by flying fragments.
- (d) The tests available show that a laminated plastic goggle was by far the best so far as physical protection is concerned. Many more aspects of the matter will have to be considered and much more work will have to be done but the experimental work to date indicates quite clearly that the laminated plastic goggle is the one that provides the maximum degree of safety.
- (e) Molten metal does not appear to wet plastic surfaces but it does wet metal surfaces and glass surfaces and adheres to them. It appears at this stage, therefore, that plastic lenses should not be mounted in metal rims because molten splashes will adhere to the rim and may then set fire to the plastic. This aspect of the matter clearly needs further consideration and probably further experimental work."

At the end of the second stage of our work we embodied our conclusions in paragraph 42 of our Second Report which reads as follows:

- "42. (1) The conclusions reached in our First Report were confirmed and amplified.
- (2) Impact tests can be done with cold solid projectiles so long as the effects of heat are estimated by means of other tests.
 - (3) Impact testing should be done at a velocity at least as high as 20,000 feet per minute.
 - (4) All toughened and laminated glass lenses completely failed the impact test. They were also cracked and broken when tested against molten projectiles. They are therefore unsuitable for use in foundries.
 - (5) Certain laminated plastic lenses and certain double plastic lenses withstood the impact test and were also satisfactory against heat tests. Other types of plastic lenses may well be developed in the future but we have no doubt now that existing and easily available plastic materials will give complete protection against the fairly severe tests that we have applied. We take the view, therefore, that lenses of these types are suitable for use in foundries.
 - (6) These plastic lenses will have to be securely mounted in suitable frames and the testing of complete goggles and spectacles is therefore the next stage of our work.
 - (7) The ophthalmological properties of the selected lenses must now be investigated and work has already started on this aspect of the matter."

3. These conclusions have remained unchanged by our subsequent work which has merely served to amplify and confirm them in so far as it has borne on them at all. This Third Report deals chiefly, however, with the development of frames which would be strong enough to hold the lenses against the impact test on which the lenses themselves have already been selected.

PRELIMINARY CONSIDERATIONS

4. When we drafted our Second Report on the completion of the second stage of our work we had:

- (a) Designed, constructed, calibrated and used a spring-loaded test machine with cold solid projectiles, hot solid projectiles and molten metal projectiles striking the lenses under test at velocities of 7 to 10 feet per second.
- (b) Designed, constructed, calibrated and used a test rig with cold solid projectiles striking the lenses under test at velocities of 390 feet per second (approximately 266 miles per hour).
- (c) Examined the work of Major Reid who had designed, constructed, calibrated and used a rig with cold solid projectiles striking the lenses under test at velocities of 700 - 900 feet per second (approximately 477 - 613 miles per hour).
- (d) Designed, constructed, calibrated and used a needle test machine.
- (e) Designed, constructed and used an empirical rig by means of which burning tests could be applied to plastic lenses.

These tests had led us to the conclusion that glass should not be used for protection against molten metal, neither should it be used to protect against flying particles which might easily possess large amounts of energy. We had also developed several double plastic lenses which withstood all our tests. Finally we had been informed that there was good reason to believe that these double plastic lenses would satisfy the British Standard ophthalmological requirements. Two things therefore remained to be done. They were:

- (a) To modify the test equipment so that complete spectacles, goggles or face shields could be tested, and
- (b) To design spectacles, goggles or face shields which would withstand the tests.

THE IMPACT TEST RIG

5. We used the air rifle described in our Second Report modifying the rig to take a head on which all types of protective equipment could be mounted. The orbits were machined out so that plasticine could be inserted before testing. This would indicate whether or not the "eye" had been struck by the missile or by any part of a broken goggle after testing. The arrangement is shown in Figures 19 - 22. Figure 19 shows the rig as it is actually used for testing. Figure 20 shows the guard open after the rifle has been removed. A pair of goggles is mounted on the head and a rod has been inserted through the rifle muzzle locating cylinder. This rod points to the spot on which the missile will strike the goggle when testing. It is used therefore to "sight" the rifle so that any part of the goggle can be tested. Figure 21 is a close-up view of the head and the end of the rod. This illustration also shows the screws and wheels by means of which the head is moved either horizontally or vertically so that the point of impact of the missile can be selected. Figure 22 shows a line drawing of the apparatus.

6. During the second stage of our work we had mounted the lenses rigidly between steel retaining rings when they were being tested. This was done because the object at that stage was to test the materials of which the lenses were made. It was important therefore that no movement of the lens be allowed at the moment of impact. Had this occurred the results would not have indicated the behaviour of the material under test but the combined resistance due to the material and the movement. It would not then have been possible to separate the two factors. It may be unlikely that any such movement would have had much effect at an impact velocity of 390 feet per second but nevertheless mechanical tests on the strength of materials should not include two unknown factors.

For the part of the work described in this Report we decided that we should test the goggles in conditions as near as possible to those in which they would be used. We made this decision because we already knew that the lens material was strong enough to withstand the impact test. We were no longer testing the strength of a material but the resultant of material strength, constructional strength, resilience due to design, movement on impact and so on.

We hold the view that both types of impact test should always be done so that material will not be used for the protection of eyes unless it is strong enough to resist the impact when mounted rigidly and that goggles (or other eye protection) will not be used unless they are of such design and construction that they will resist the impact when mounted "as worn".

IMPACT TESTS

7. We discovered four suitable lenses as a result of our earlier work but we emphasised at the time that these lenses may not be the only materials which are satisfactory for the purpose adding the comment that "there may be other materials which we have not tested or of which we are not aware which may give equal or better results". We did not however think that it was any part of our work to explore the whole range of possible materials once we had found materials and lenses which would provide the kind of protection we envisaged in our First Report. We have treated the third phase of our work in the same manner and in consequence we used only one of the four types of lenses known to be suitable on previous impact tests because goggle frames which would hold this type of lens against the tests could presumably be made to hold other types of lenses as well. We also thought that our work would be completed if we could develop one form of eye protection that would satisfy all our tests, leaving to the industry concerned the development of other and perhaps better forms. We decided therefore that we should try to find one such form of spectacle, one such form of goggle and one such form of face screen. We have not found a suitable pair of spectacles but we have developed a face screen which looks exceedingly promising and we have also developed one form of goggles which will satisfy all our tests. This is not to say that other forms of eye protection might not be made which will be as good or even better. We hope they will. But we now have one form of goggles which meets the tests we have applied and because those tests are so far in excess of anything previously used in industry we think that the greatly superior form of eye protection now available should be used as a minimum.

IMPACT RESULTS

Spectacles

8. A few spectacles were tested but these all failed for one reason or another and we have insufficient information to warrant any real discussion of the matter. We included details of some tests (Table I) as an indication of the sort of results we obtained.

Face Screens

9. Two types of face screen were tested. Both were made of "Celastoid" and consisted of two layers, the front layer being 0.050 inches thick and the back layer 0.080 inches thick. The two layers were not stuck together in any way and so we called them "double screens" to distinguish them from a true laminated screen in which the layers would be held together by an adhesive. The difference between the two screens was that the first one was curved in the normal manner whilst the second one had a flat front which was bent through 90 degrees at each side in order to give two flat side wings.

10. The curved screen was used for the first series of tests (numbers 33 to 34, Table II and footnote). Although the curved screen resisted the first shot of each test it failed on the second or third shot when a series of shots were fired at the same spot on the screen one after the other. We knew from earlier work that a double lens of this material in these thicknesses would not fail in this fashion even when it was mounted rigidly. We had thought therefore that the larger screen in a flexible mounting would not have failed. This result may have

been due to the fact that the shot struck the screen on a convex surface and so altered the internal stress distribution sufficiently to cause failure. To test this suggestion we had the flat screen made and this was tested (numbers 50 to 56, Table II). The first four shots were made in a horizontal line at eye level and the screen withstood them (Figure 23). The next three shots were made one higher and two lower on the screen and on each occasion it failed (Figure 23). These failures may have been due to the fact that the two layers of material were not in contact on the rather crudely made screen which was tested.

11. All that can be said as a result of these tests is that it would seem that a suitable screen could be constructed because the two attempts we made were almost successful.

Goggles

12. We first tested a series of different types of goggles in an effort to discover the most promising type even if they all failed. These types are given in Table III and the Model numbers there shown are used throughout this Report.

13. It will be seen from Table IV that all these goggles showed some promise and it appeared that standard type goggles might be modified to meet the impact test. We at once discarded those with metal fittings because we knew they would not satisfy our molten metal tests even if they passed all the impact tests. Whilst they might therefore be suitable in those industries in which no molten metal is used they would not be good enough for foundries. We discarded other models because the side wings were opaque and this left us with Model 204 which was made from a clear cellulose acetate.

14. We then did a further series of tests on Model 204 (Table V). We added an extra lens because our selected lens was so thin as to be loose in the goggle cup. The extra lens was just thick enough to take up the slack in the mounting. We found on testing that the front retaining ring was cracked on the first shot which confirmed the earlier result (number 11, Table IV). Evidently the lens "dished" under the impact and transmitted the force of the blow in a forward direction (i.e., opposite to the direction of travel of the shot) cracking the retaining ring. The lens was undamaged and the retaining ring did not leave the threads which held it. Thereafter a further seven shots in the same place on the same lens did no more damage. It appeared therefore that the resilience introduced by the cracked ring was sufficient to withstand the test.

15. At this stage in the work we introduced a P.V.C. washer into the assembly because we thought that this washer might provide sufficient resilience for the impact test. The washer could be placed on the goggle cup behind the lens or between the two layers of the double lens or in front of the lens immediately behind the retaining ring. We tried it in all these positions. Table VI gives the results. It was evident that the best place for the washer was behind the lens but even with the washer in position the retaining ring was liable to be cracked or prised forward on its threads or both under the impact of the shot.

16. We decided therefore to try a nylon retaining ring because we were informed that nylon would be stronger and we were certain that very little extra strength would be needed. The Model 204 goggle fitted with a P.V.C. washer behind the

double lens and a nylon retaining ring (see Figure 24) was then tested with the results given in Table VII. It will be seen from this Table that the pair tested needed eight consecutive shots on the same spot in the centre of one lens to do any material damage. Even then the shot did not penetrate as only the top lens cracked. On close examination of other specimens we found that a slight internal crack developed in the acetate cup after the first shot but the goggles were virtually undamaged and we did not succeed in penetrating them at all or in breaking them in any way under eight shots. We therefore considered that this goggle was satisfactory in so far as impact properties were concerned.

HOT METAL TESTS

17. We had introduced a nylon retaining ring in the goggle which we had finally developed. In consequence we tested the nylon against heat before coming to a final decision.

Molten Metal Test

18. Using the molten metal test described in our First Report with a projectile consisting of 145 grams of molten iron at a temperature of 1,400 degrees C and with the specimen placed at three inches from the stop plate, we found that the nylon was satisfactory. The nylon was not wetted by the molten metal which did not adhere to the plastic specimen. Some of the metal did adhere to the cold steel holding ring and this metal was in contact with the nylon for about one minute. There was no flame and the nylon did not burn. A little of this metal solidified on the nylon without burning through it.

Burning Test

19. We also submitted the nylon to the burning test described in our First Report using a circle of nylon 45 mm. in diameter and 0.040 inches thick. The red hot ball penetrated in 18 seconds but there was no flame.

MISCELLANEOUS TESTS

Impact Test on Nylon

20. We tested the 45 mm. nylon circles in the material testing air rifle rig described in our Second Report. Using two layers each 0.040 inches thick the first centre shot did not damage either layer. The first layer was then taken out and retested by itself. This 0.040 inches thick circle of nylon which had already been tested and therefore strained now withstood one further shot without damage but was penetrated by the second further shot (i.e., the third shot in total). The other layer which had been tested as a double lens was also subsequently tested alone and was penetrated by the first further shot (i.e., by the second shot in total).

Misting

21. When we thought that Model 204 could be successfully modified, we immediately arranged that the goggles should be used in a foundry in order to discover the reaction of the wearers. These goggles were the standard Model 204 (Table III) with the exception that double lenses were used. The front lens was made of coloured material for men handling molten metal. Anti-mist solution was provided for the convenience of the wearers but no impact tests were done on treated lenses.

Ten cupola keepers have worn this selected goggle since November, 1959. They regard it as the best type of goggle they have tried and they want to continue to use it. They say that there is slight misting sometimes between the lenses and also that when they perspire the rubber bridge piece connecting the eye cups tends to slip allowing the whole goggle to move down the face. One other man used the goggles on casting but he preferred a visor type of goggle although he could give no reason for his preference.

CONCLUSIONS

22. Our earlier conclusions remain unaltered and the last phase of the work has led us to the following additional conclusions:

- (1) That a suitable rig to test any form of eye protection can be constructed relatively easily.
- (2) That this test rig should be used in addition to the other tests described in our First and Second Reports.
- (3) That these tests are so far in excess of any previously used in industry that in view of the greatly superior form of eye protection now available they should be used as a minimum in foundries.
- (4) That a moulded cellulose acetate frame goggle fitted with double "Celastoid" lenses backed by a P.V.C. washer and held in position by a nylon retaining ring has withstood all our tests.
- (5) That this new form of goggle has been worn satisfactorily by 10 cupola keepers since November, 1959.
- (6) That other forms of goggles appear to be almost good enough to satisfy the impact test. Some of these goggles might be suitable for use against molten metal and some were quite unsuitable but further development work is needed to provide alternative forms of suitable goggles.
- (7) That efforts should be made to develop suitable visor type goggles and suitable face screens.

ACKNOWLEDGMENTS

23. We are indebted to Mr. Livermore of the Midland Motor Cylinder Company Limited for facilities for practical work; to the Directors of B.S.A. (Guns) Limited for the prototype air rifles; to British Celanese Limited for lens specimens; to Mr. C. T. Knott of William Stephens Limited for his interest and assistance in the work; and to the Directors of William Stephens Limited for many of the devices which we have tested. Without all this assistance we could not have done the work.

(Signed) A. W. BUSHELL
W. B. LAWRIE

TABLE I

Impact Test on Spectacles

Serial Number	Eye Protection	Position of Shot	Remarks
1	Metal frame spectacles	1 shot in centre of lens	Lens undamaged but knocked out of frame.
2	Metal frame spectacles	1 shot on spectacle bridge	Frame distorted; right lens knocked back; left lens moved forward; neither lens left frame.
3	Metal frame spectacles with side protection.	1 shot in centre of lens	No damage.
4	Metal frame spectacles with side protection	1 shot near bridge	Lens undamaged but driven out of frame.
5	Metal frame spectacles with side protection	1 shot near hinge of side piece	Lens driven out of frame (lens undamaged).
19	Model 501 Acetate frame Acrylic lens	1 shot in centre of lens	Lens broken and shot penetrated.
20	Model 501 Acetate frame Acrylic lens	1 shot on hinge of side piece	Spectacles knocked off head. No damage beyond slight crack in acetate frame on back.
21	Model 501 Acetate frame Acrylic lens	1 shot on bridge	Bridge broken; spectacles fell off head in two pieces.

TABLE II

Impact Tests on Face Screens

Serial Number	Eye Protection	Position of Shot	Remarks
33*	Curved double screen ("Celastoid", 0.050" thick front and 0.080" thick back)	1 shot on centre line over bridge of nose	No damage.
34*	Curved double screen ("Celastoid", 0.050" thick front and 0.080" thick back)	1 shot on same place as for Test 33 and on same screen	The impacted sheet (0.050") cracked and the back sheet (0.080" thick) broke—a piece being dislodged from the screen. The ball did not penetrate.
50	Flat double screen ("Celastoid", 0.050" thick front and 0.080" thick back)	Shot No. 1 (Fig. 5)	No damage.
51	Flat double screen ("Celastoid", 0.050" thick front and 0.080" thick back)	Shot No. 2 (Fig. 5)	No damage.
52	Flat double screen ("Celastoid", 0.050" thick front and 0.080" thick back)	Shot No. 3 (Fig. 5)	No damage.
53	Flat double screen ("Celastoid", 0.050" thick front and 0.080" thick back)	Shot No. 4 (Fig. 5)	No damage.
54	Flat double screen ("Celastoid", 0.050" thick front and 0.080" thick back)	Shot No. 5 (Fig. 5)	Front lens penetrated, probably because of $\frac{1}{4}$ " air gap between front and back.
55	Flat double screen ("Celastoid", 0.050" thick front and 0.080" thick back)	Shot No. 6 (Fig. 5)	Front layer broken off below point of impact.
56	Flat double screen ("Celastoid", 0.050" thick front and 0.080" thick back)	Shot No. 7 (Fig. 5)	Both back and front layers broken and penetrated, probably because of $\frac{1}{4}$ " air gap.

* Other shots were tried in different positions on the same screen. All results were similar, the screen failing in the same way, on the second or third shot.

TABLE III

Types of Goggles Tested

Model Number	Description
206	Moulded cellulose acetate frame goggles. Adjustable ball-chain bridge. Metal ventilators. 2" diameter lenses in moulded cellulose acetate plastic screwed rims.
204	Moulded clear cellulose acetate plastic frame goggles. Designed to fit over ordinary corrective spectacles. Adjustable strap nose bridge. 2" diameter lens in cellulose acetate plastic moulded screwed rims.
672	Fabricated black fibre frame goggles edged with P.V.C. material. Adjustable strap nose bridge. 2" diameter lenses in metal base rings with cellulose acetate moulded plastic screw top rims.
540	Fabricated aluminium frame goggles edged with P.V.C. material. Adjustable strap nose bridge. 2" diameter lenses in metal base rings with cellulose acetate moulded plastic screw top rims.
541	Fabricated clear plastic frame goggles edged with P.V.C. material. Adjustable strap nose bridge. 2" diameter lenses in brass screwed rims, black, oxidised.
432	Fabricated 30 mesh wire gauze frame goggles. Designed to fit over corrective spectacles. Edges bound with leather strip. Non-adjustable nose bridge. 2" diameter lenses in metal screwed rims (aluminium).
106	Fabricated clear plastic frame goggles designed to fit over corrective spectacles. Edges bound with P.V.C. material. Adjustable strap nose bridges. 2" diameter lenses in metal screwed rims, oxidised.

TABLE IV

Impact Tests on a variety of Goggles

Serial Number	Eye Protection	Position of Shot	Remarks
6	206	1 shot in centre of lens	Lens undamaged. Retaining ring cracked.
7	206	1 shot on frame near bridge	Lens undamaged. Retaining ring cracked.
8	672	1 shot in centre of lens	Lens undamaged. Retaining ring forced off its thread and the lens left the frame. Both ring and lens forced off in a forward direction (i.e., away from eye of wearer).
9	672	Lens and ring replaced after Test 8 and second shot in centre of lens	Lens undamaged. Retaining ring forced off some threads, moving forward as in Test 8. Ring held by last thread so, unlike No. 8, neither ring nor lens left goggle frame.
10	672	1 shot on frame	Retaining ring slightly cracked and forced off its threads. Ring and lens left goggles in a forward direction (i.e., away from wearer's eye).
11	204	1 shot in centre of lens	The lens was loose in the frame as it was not thick enough. No damage to lens. Retaining ring cracked but not displaced from goggle.
12	204	1 shot on frame (near bridge)	Retaining ring cracked and broken and forced off its threads. No damage to lens, but ring and lens forced off in a forward direction (i.e., away from wearer's eye).
13	540	1 shot in centre of lens	Lens undamaged. Retaining ring loosened but neither ring nor lens displaced from goggle.
14	540	1 shot on frame (near bridge)	Retaining ring battered; lens undamaged; both ring and lens remained in position.

TABLE IV (*contd.*)

Impact Tests on a variety of Goggles

Serial Number	Eye Protection	Position of Shot	Remarks
15	432	1 shot in centre of lens	No damage.
16	432	1 shot on frame (near bridge)	Retaining ring battered; lens undamaged; both ring and lens remained in position.
17	106	1 shot in centre of lens	Lens undamaged; retaining ring loosened but lens and ring remained in position.
18	106	1 shot on frame (near bridge)	Lens undamaged; retaining ring battered but ring and lens remained in position.
22	541	1 shot in centre of lens	Lens undamaged but driven back a little in goggles. The lens remained in the goggles and nothing would have damaged the eye of a wearer.
23	541	1 shot on frame (near bridge)	No damage.
24	541	1 shot in same place as in Test 23 and on same goggle	Lens undamaged. Retaining ring and lens forced off in a forward direction (i.e., away from eye of wearer). After the test the ring was screwed back and the goggles were still serviceable.

TABLE V

Impact Test on Goggle 204

Serial Number	Eye Protection	Position of Shot	Remarks
25	204	1 shot in centre of lens	Result as for Test 11 (Table IV). Lens undamaged; retaining ring cracked but not displaced from goggle.
26	Pair of goggles used for No. 25 were tested again with the cracked retaining ring	1 shot in centre of lens	Lens undamaged; no further damage to retaining ring which was not displaced from goggle.
27	Pair of goggles used for No. 25 were tested again with the cracked retaining ring	1 shot in centre of lens	Lens undamaged; no further damage to retaining ring which was not displaced from goggle.
28	Pair of goggles used for No. 25 were tested again with the cracked retaining ring	1 shot in centre of lens	Lens undamaged; no further damage to retaining ring which was not displaced from goggle.
29	Pair of goggles used for No. 25 were tested again with the cracked retaining ring	1 shot in centre of lens	Lens undamaged; no further damage to retaining ring which was not displaced from goggle.
30	Pair of goggles used for No. 25 were tested again with the cracked retaining ring	1 shot in centre of lens	Lens undamaged; no further damage to retaining ring which was not displaced from goggle.
31	Pair of goggles used for No. 25 were tested again with the cracked retaining ring	1 shot in centre of lens	Lens undamaged; no further damage to retaining ring which was not displaced from goggle.
32	Pair of goggles used for No. 25 were tested again with the cracked retaining ring	1 shot in centre of lens	Lens undamaged; no further damage to retaining ring which was not displaced from goggle.

TABLE VI

Impact Tests on Goggle 204 with P.V.C. Washer

Serial Number	Eye Protection	Position of Shot	Remarks
35	204 with P.V.C. washer in front of lens	1 shot in centre of lens	Lens undamaged; retaining ring forced off its threads.
36	204 with P.V.C. washer in front of lens	1 shot in centre of lens	Lens undamaged; retaining ring forced off its threads and cracked.
37	204 with P.V.C. washer in front of lens	1 shot in centre of lens	Lens undamaged; retaining ring forced off its threads and cracked.
38	204 with P.V.C. washer behind lens	1 shot in centre of lens	Lens undamaged; retaining ring prised forward very slightly at bottom. The ring was cracked but did not leave the goggle.
39	204 with P.V.C. washer behind lens	1 shot in centre of lens	Lens undamaged; retaining ring slightly cracked, but did not leave the goggle.
40	204 with P.V.C. washer behind lens	1 shot in same place as Test 39 on the same goggle	Lens undamaged; retaining ring cracked and forced off its threads. Ring left the goggle.
41	204 with P.V.C. washer behind lens	1 shot in centre of lens	Lens undamaged; retaining ring forced off its threads. The ring left the goggle.
42	204 with P.V.C. washer between the lenses	1 shot in centre of lens	Front 0.050" lens cracked; back lens undamaged; retaining ring cracked. Ball did not penetrate and all stayed in position.
43	204 with P.V.C. washer between the lenses	1 shot in centre of lens	Lens undamaged; retaining ring cracked; all stayed in position.
44	204 with P.V.C. washer between the lenses	1 shot in centre of lens	Front 0.050" lens broken; back lens undamaged; retaining ring cracked and forced off its threads. The ring left the goggle.
45	204 with P.V.C. washer between the lenses	1 shot in centre of lens	Front 0.050" lens broken; back lens undamaged; retaining ring cracked and forced off its threads. The ring left the goggle.

TABLE VI (contd.)

Impact Tests on Goggle 204 with P.V.C. Washer

Serial Number	Eye Protection	Position of Shot	Remarks
46	204 with P.V.C. at back of lens	1 shot in centre of lens	Lens undamaged; retaining ring cracked; all stayed in position.
47	204 with P.V.C. at back of lens	1 shot in same place as Test 46 and on same goggle	Lens undamaged; retaining ring forced off its threads. The ring left the goggle.
48	204 with P.V.C. at back of lens	1 shot in centre of lens	No damage.
49	204 with P.V.C. at back of lens	1 shot in same place as for Test 48 and on same goggle	Lens undamaged; retaining ring forced off its threads. The ring left the goggle.

TABLE VII

Impact Tests on Goggle 204 with P.V.C. Washer and Nylon Retaining Ring

Serial Number	Eye Protection	Position of Shot	Remarks
57	204 with nylon ring and P.V.C. washer behind lens	1 shot in centre of lens	No damage.
58	204 with nylon ring and P.V.C. washer behind lens	1 shot in same place as Test 57 and on same goggle	No damage.
59	204 with nylon ring and P.V.C. washer behind lens	1 shot in same place as Test 57 and on same goggle	No damage.
60	204 with nylon ring and P.V.C. washer behind lens	1 shot in same place as Test 57 and on same goggle	No damage.
61	204 with nylon ring and P.V.C. washer behind lens	1 shot in same place as Test 57 and on same goggle	No damage.

TABLE VII (contd.)

Impact Tests on Goggle 204 with P.V.C. Washer and Nylon Retaining Ring

Serial Number	Eye Protection	Position of Shot	Remarks
62	204 with nylon ring and P.V.C. washer behind lens	1 shot in same place as Test 57 and on same goggle	No damage.
63	204 with nylon ring and P.V.C. washer behind lens	1 shot in same place as Test 57 and on same goggle	No damage.
64	204 with nylon ring and P.V.C. washer behind lens	1 shot in same place as Test 57 and on same goggle	This eighth shot on the same spot broke the front 0.050" lens; back lens undamaged; nylon retaining ring undamaged. Some slight internal cracking in acetate cup. All stayed in position.
65	204 with nylon ring and P.V.C. washer behind lens	1 shot in centre of lens	Lens undamaged; nylon retaining ring undamaged. Very slight internal crack in acetate cup. All stayed in position. Goggle virtually undamaged.
66	204 with nylon ring and P.V.C. washer behind lens	1 shot in same place as Test 65 and on same goggle	Lens undamaged; nylon retaining ring undamaged. Very slight internal crack in acetate cup. All stayed in position. Goggle virtually undamaged.
67	204 with nylon ring and P.V.C. washer behind lens	1 shot on nylon ring near bridge	Retaining ring broken. Lens undamaged. Nothing penetrated.
68	204 with nylon ring and P.V.C. washer behind lens	1 shot on acetate bridge pad	Acetate bridge pad broken. No other damage to goggle. (This shot would have penetrated the face of the wearer below eye level.)
69	204 with nylon ring and P.V.C. washer behind lens	1 shot on nylon retaining ring	No damage.
70	204 with nylon ring and P.V.C. washer behind lens	1 shot on lens $\frac{1}{8}$ " from nylon retaining ring	No damage.
71	204 with nylon ring and P.V.C. washer behind lens	1 shot on nylon ring	Retaining ring broken. Lens undamaged.

APPENDIX V

CONTENTS

	Page
Fourth Interim Report of the Sub-Committee of the Joint Advisory Committee on Foundry Goggles	124
Membership of the Sub-Committee of the Joint Advisory Committee on Foundry Goggles	124
INTRODUCTION	125
THE EFFECTS OF STRAIN ON THE LENSES	126
THE EFFECTS OF FLUIDS ON THE LENSES	127
THE IMPACT VALUE OF THICKER DOUBLE LENSES	129
THERMO PLASTIC POLYCARBONATE MATERIAL	129
Preliminary Impact Tests	129
Impact Testing at 390 feet per second	130
Impact Testing at 500 feet per second	133
The Face Screen	134
CONCLUSIONS	135
ACKNOWLEDGMENTS	135

**FOURTH INTERIM REPORT OF THE SUB-COMMITTEE OF
THE JOINT ADVISORY COMMITTEE ON FOUNDRY GOGGLES**

Members of Sub-Committee

Mr. A. W. Bushell

Mr. W. B. Lawrie, M.B.E., M.Sc., F.R.M.S., A.I.M.

FOURTH INTERIM REPORT OF THE SUB-COMMITTEE OF THE JOINT ADVISORY COMMITTEE ON FOUNDRY GOGGLES

Mr. H. Woods,
Chairman,
Joint Advisory Committee on Foundry Goggles

INTRODUCTION

1. We have now concluded the fourth stage of the work on foundry goggles and so we offer you our Fourth Report. Our First Report described a method of testing lenses with molten metal together with a low velocity impact test and a needle test. Later we added a high velocity impact test and a burning test which were described in our Second Report. At this stage of the work we had also found a double plastic lens which withstood all our tests. During the third stage of our work we modified the high speed impact testing rig so that it would take goggles and face screens rather than lenses and we proceeded to develop goggle frames which would hold the selected lenses against the impact of the missiles used for testing. This work which was described in our Third Report resulted in a cup type goggle which withstood all our tests and which has now been in use in one foundry under our supervision for about two years.

2. At the end of this work we found two of the selected lenses which failed under test. We therefore proceeded to the fourth stage of the work with the following objects in view:

- (a) to determine the cause of the failure of the two lenses mentioned above;
- (b) to determine the effects of moisture on the lenses;
- (c) to explore the possibility of designing other types of protection because we thought that the cup type of goggle would not be acceptable to everybody and
- (d) to examine other materials for use as lenses.

3. The work occupied us for a considerable time but when it was completed we had discovered a new material and constructed a prototype face screen which withstood higher impact tests than the goggles described in our Third Report. We therefore delayed this report until we were in a position to make more of these screens for further testing. This has in fact involved a delay of some months owing to the difficulty of obtaining suitable tools with which to make the screens but we waited because we thought we should test the kind of screen that might be used and base our conclusions on the results of these tests rather than basing them on tests performed on a single prototype screen which had been constructed by hand and without the proper tools.

4. In the meantime we tested other types of goggles and we include the results of some of these tests in this report.

THE EFFECTS OF STRAIN ON THE LENSES

5. The material of which the double lenses was made may be strained during the manufacturing process and we assumed that this strained material would

be weaker than the normal unstrained material. This internal strain may easily be detected by examining the material in polarised light and so we decided to test a series of double lenses which had been made from strained material. We did not succeed in obtaining sufficient strained material in the 0.050" thickness but with the assistance of the manufacturers we did collect enough strained material in the 0.080" thickness to undertake a series of tests.

6. The lenses were tested on the lens impact rig described in our Second Report. The first series was done on double lenses consisting of 0.050" unstrained material with 0.080" strained material. The lenses were 2" diameter Celastoid and each was subjected to one shot in the centre. The projectile was a $\frac{1}{4}$ " steel ball moving at 390 feet per second. The results are given in Table I.

TABLE I

Double lenses, 0.050" (unstrained) with 0.080" (strained) Celastoid. Impact Test in lens rig. Projectile velocity 390 feet per second. One shot only in centre of each specimen.

Serial No.	Remarks	Serial No.	Remarks
1	Undamaged.	11	Front lens broken.
2	Penetrated.	12	Penetrated.
3	Front lens cracked.	13	Front lens cracked.
4	Penetrated.	14	Penetrated.
5	Penetrated.	15	Penetrated.
6	Front lens cracked.	16	Penetrated.
7	Undamaged.	17	Penetrated.
8	Undamaged.	18	Undamaged.
9	Front lens cracked.	19	Penetrated.
10	Penetrated.	20	Penetrated.

During these 20 tests the projectile penetrated 55 per cent of the lenses (11 lenses), cracked or broke 25 per cent (5 lenses) of the front lenses and only 20 per cent (4 lenses) remained undamaged. It was evident, therefore, that the double Celastoid lens was much weaker if the 0.080" thick lens was strained.

7. One test only was done when using a double lens consisting of two strained pieces of Celastoid each 0.080" thick. The result appears in Table II. This suggests that the thicker double lens is still unsatisfactory if it is made of strained material.

TABLE II

Double lens 0.080" (strained) with 0.080" (strained) Celastoid Impact Test in lens rig. Projectile velocity 390 feet per second. One shot only in centre of specimen.

Serial No.	Remarks
21	Front lens broken.

8. There was some difficulty in collecting strained material for these tests and it appeared that the thinner material (0.050") was by no means as likely to be strained as the thicker material (0.080"). There can be no doubt that the strained material is weaker than the normal unstrained material. When using the normal 0.050"/0.080" double lenses the presence of strain in the 0.080" part of the lens so weakened the composite lens that it failed the impact test. When using a 0.080"/0.080" double lens the ball did not penetrate but even this thicker lens was inferior to the 0.050"/0.080" lens made of unstrained material.

9. No further tests were done because strain can easily be detected by examining the material in polarised light and it was evident that strained lenses were significantly weaker than unstrained lenses. We concluded that the presence of strain was the cause of a failure of the two lenses which had led to this work and that in consequence all lenses should be examined for strain and that no strained lenses should be used.

THE EFFECTS OF FLUIDS ON THE LENSES

10. In addition to the two lenses already mentioned a further lens failed on the impact test after treatment with a demisting fluid. This failure may have been due to internal strain in the lens material but it may have been due to the presence of fluid on the lens. We decided, therefore, to investigate the effects of fluids on unstrained lenses.

11. We used water, an anti-misting compound and oil although most of the tests were done with oil because it was easier to cover the surfaces with oil than with other fluids and the results did not seem to vary greatly with the fluid used. Some surfaces were covered by rubbing in oil with the finger-tip and in other instances the lenses were soaked in the fluid for some hours.

12. The first series of tests was done on double Celastoid lenses consisting of 0.050" (unstrained) with 0.080" (unstrained) lenses after a continuous film of oil had been placed between them. The results are given in Table III which shows that over 80 per cent (5 out of 6) of the normal 0.050"/0.080" unstrained double lenses failed when there was a continuous film of oil between the lenses.

TABLE III

Double lenses, 0.050" (unstrained) with 0.080" (unstrained) Celastoid and continuous film of oil between. Impact test in lens rig. Projectile velocity 390 feet per second. One shot only in centre of each specimen.

Serial No.	Remarks	Serial No.	Remarks
44	Front lens cracked.	47	Front lens cracked.
45	Front lens cracked.	48	Undamaged.
46	Front lens cracked.	49	Front lens cracked.

13. A second series of tests was then done using a double lens consisting of two 0.080" Celastoid lenses with a continuous film of oil between them. The results are given in Table IV.

TABLE IV

Double lenses 0.080" (unstrained) with 0.080" (unstrained) Celastoid and continuous film of oil between. Impact test in lens rig. Projected velocity 390 feet per second. One shot only in centre of each specimen.

Serial No.	Remarks	Serial No.	Remarks
43	Undamaged.	59	Undamaged.
50	Undamaged.	60	Undamaged.
51	Undamaged.	61	Undamaged.
52	Undamaged.	62	Undamaged.
53	Undamaged.	63	Undamaged.
54	Undamaged.	64	Undamaged.
55	Undamaged.	65	Undamaged.
56	Undamaged.	66	Undamaged.
57	Front lens cracked.	67	Undamaged.
58	Back lens broken.	68	Undamaged.

14. Here 10 per cent (2 out of 20) of the 0.080"/0.080" unstrained double lenses failed when there was a continuous layer of oil between them.

15. Other tests were done on the 0.050"/0.080" unstrained double lenses and also on the 0.080"/0.080" unstrained double lenses when there is oil on the front surface of the front lens and oil on the back surface of the back lens but no oil between the lenses. Each series consisted of 20 lenses and each lens was subjected to one blow in its centre from the $\frac{1}{4}$ " ball moving at 390 feet per second. These lenses remained undamaged and so it appears that oil on front or back surfaces has no significant effect on the behaviour of the double lens. Further tests were done using anti-misting fluids and water and similar results were obtained.

16. The general result of these tests was that a fluid had no effect on the impact value if it were present on the front face or the back face (or both) of the double lens. On the contrary, however, it reduced the impact value if it were present as a continuous film between the lenses. It had already been shown that laminated lenses did not appear to be as good as double lenses and this new finding was therefore in line with the earlier results. Presumably the continuous film of fluid between the lenses turned the double lens into a fluid laminated lens and in consequence reduced its strength to impact. It was already known that the dry double lens passed the impact test at 390 feet per second but failed at 500 feet per second. The critical range is therefore between 390 and 500 feet per second. The fluid laminated lens has a lower critical range which is below 390 feet per second for the 0.050"/0.080" lens and about 390 feet per second for the 0.080"/0.080" lens. In no case, however, was the strength so reduced that the test missile actually penetrated the fluid laminated lens although many of these lenses were so damaged as to be judged to have failed the test.

THE IMPACT VALUE OF THICKER DOUBLE LENSES

17. The double lens originally selected consisted of two layers of Celastoid respectively 0.050" and 0.080" in thickness. During this fourth stage of the work, however, a heavier double lens consisting of two layers of Celastoid respectively 0.080" and 0.080" had been used (see Table IV) and so we decided to subject this lens to further tests both in the lens testing rig described in our Second Report to test the material, and also in the goggle testing rig described in our Third Report in order to test the full goggle. In these two series of tests, dry unstrained lenses were used throughout in order to obtain results in normal conditions.

18. In the first place a series of 20 tests was done using dry 0.080"/0.080" lenses and subjecting each specimen to one blow at its centre from the $\frac{1}{4}$ " ball at 390 feet per second. All the lenses were undamaged so that the 0.080"/0.080" lens will withstand the impact test as well as did the 0.050"/0.080" lens.

19. The 0.080"/0.080" lenses were then fitted into the standard cup goggles and submitted to one blow at the centre from the $\frac{1}{4}$ " ball at 390 feet per second in the goggle testing rig. Four such tests were done and in each case the lens was undamaged but the nylon retaining ring, the washer and the lens were all driven off the goggle frame in a forward direction (i.e., away from the eye of the wearer) and nothing penetrated to the plasticine eye in the test rig. It was evident that the goggle frame would not hold the thicker and stiffer double lens. This thicker lens did not allow the nylon ring to be screwed home and probably the last thread on the retaining ring was not engaging. A longer ring was, therefore, made and the tests repeated when it was found that the new goggle would withstand the test.

20. One advantage of this type of goggle may be that it cannot be incorrectly assembled because the two lenses are similar in thickness.

THERMO PLASTIC POLYCARBONATE MATERIAL

21. We had not been particularly successful in designing other types of eye protection apart from the cup goggle when using double lenses of the selected material and we thought this a matter of some importance because we hoped to be able to accommodate personal preferences in the wearers. In particular we had found difficulty in producing a face screen which would satisfactorily and completely withstand the impact test. This difficulty appeared to be due to the necessary curvature of a face screen and to the fact that it was no easy matter to maintain contact between the relatively large surfaces of a double screen. We were, therefore, looking for other materials and we decided to try a polycarbonate material when we were informed that it possessed an unusual combination of properties. We have tested a material sold commercially under the name "Makrolon" and from it we have made a face screen which will withstand our tests.

Preliminary Impact Tests

22. The material was first tested in the lens impact rig described in our Second Report. The tests were made using two lenses respectively 0.75 mm. (approximately 0.030") and 1 mm. (approximately 0.040") in thickness. Each lens was tested separately as a single layer of material and was subjected to one blow in

the centre from the $\frac{1}{4}$ " ball moving at 390 feet per second. Both samples withstood the test. Similar samples were then mounted in the cup type goggle and tested at 390 feet per second in the goggle testing rig. The lenses were not damaged but they were so flexible as to be forced out of the goggle frame towards the eye of the wearer. It was then decided that material 2 mm. (approximately 0.080") in thickness should be tested and subsequent work was done on this size of material.

Impact Testing at 390 feet per second

23. A prototype face screen was then made up in the polycarbonate material and tested on the goggle rig described in our Third Report at a projectile velocity of 390 feet per second. The results are given in Table V.

TABLE V

Impact Test in Goggle Rig. Projectile velocity 390 feet per second.

Serial No.	Type of Protection	Remarks
73	Screen, 2 mm. Polycarbonate	1 shot right eye—No damage.
74	Screen, 2 mm. Polycarbonate	1 shot adjacent No. 73 on same screen—No damage.
75	Screen, 2 mm. Polycarbonate	2nd shot same place as No. 73—No damage.
76	Screen, 2 mm. Polycarbonate	3rd shot same place as No. 73—No damage.
77	Screen, 2 mm. Polycarbonate	4th shot same place as No. 73—No damage.
78	Screen, 2 mm. Polycarbonate	5th shot same place as No. 73—No damage.
79	Screen, 2 mm. Polycarbonate	6th shot same place as No. 73—No damage.
80	Screen, 2 mm. Polycarbonate	7th shot same place as No. 73—No damage.
81	Screen, 2 mm. Polycarbonate	8th shot same place as No. 73—No damage.
82	Screen, 2 mm. Polycarbonate	9th shot same place as No. 73—No damage.
83	Screen, 2 mm. Polycarbonate	10th shot same place as No. 73—No damage.
84	Screen, 2 mm. Polycarbonate	11th shot same place as No. 73—No damage.
85	Screen, 2 mm. Polycarbonate	12th shot same place as No. 73—No damage.

24. It will be seen that 13 blows virtually in the same place failed to crack, break or penetrate the screen.

25. A visor type goggle was then made up with a single thickness of 2 mm. polycarbonate material and this was tested in the goggle rig at a projectile velocity of 390 feet per second.

TABLE VI

Impact Test in Goggle Rig. Projectile velocity 390 feet per second.

Serial No.	Type of Protection	Remarks
86	Visor type goggle 2 mm. Polycarbonate	1 shot right eye—No damage.
87	Visor type goggle 2 mm. Polycarbonate	2nd shot same place as No. 86—No damage.
88	Visor type goggle 2 mm. Polycarbonate	3rd shot same place as No. 86—No damage.
89	Visor type goggle 2 mm. Polycarbonate	4th shot same place as No. 86—No damage.
90	Visor type goggle 2 mm. Polycarbonate	5th shot same place as No. 86—No damage.
91	Visor type goggle 2 mm. Polycarbonate	6th shot same place as No. 86—No damage.
92	Visor type goggle 2 mm. Polycarbonate	7th shot same place as No. 86—No damage.
93	Visor type goggle 2 mm. Polycarbonate	8th shot same place as No. 86—No damage.
94	Visor type goggle 2 mm. Polycarbonate	9th shot same place as No. 86—No damage.
95	Visor type goggle 2 mm. Polycarbonate	10th shot same place as No. 86—No damage.
96	Visor type goggle 2 mm. Polycarbonate	11th shot same place as No. 86—No damage.
97	Visor type goggle 2 mm. Polycarbonate	12th shot same place as No. 86—No damage.

26. The visor type goggle withstood 12 blows on the same place without being cracked, broken or penetrated.

27. A pair of circles each 2" diameter were then cut from the 2 mm. polycarbonate sheet and one of them was fitted into each eye piece of a cup type goggle. The mounting was not an accurate fit but an existing frame was packed

with rings to form a prototype goggle. Once again the goggle was tested in the goggle rig at a projectile velocity of 390 feet per second and the results are given in Table VII.

TABLE VII

Impact Test in Goggle Rig. Projectile velocity 390 feet per second.

Serial No.	Type of Protection	Remarks
98	Cup type goggle 2 mm. Polycarbonate lens	1 shot left eye—lens broken—neither shot nor fragments of lens touched eye.
99	Cup type goggle 2 mm. Polycarbonate lens	1 shot right eye—No damage.
100	Cup type goggle 2 mm. Polycarbonate lens	2nd shot same place as No. 99—No damage.
101	Cup type goggle 2 mm. Polycarbonate lens	3rd shot same place as No. 99—No damage.
102	Cup type goggle 2 mm. Polycarbonate lens	4th shot same place as No. 99—No damage.
103	Cup type goggle 2 mm. Polycarbonate lens	5th shot same place as No. 99—No damage.
104	Cup type goggle 2 mm. Polycarbonate lens	6th shot same place as No. 99—No damage.
105	Cup type goggle 2 mm. Polycarbonate lens	7th shot same place as No. 99—No damage.
106	Cup type goggle 2 mm. Polycarbonate lens	8th shot same place as No. 99—No damage.
107	Cup type goggle 2 mm. Polycarbonate lens	9th shot same place as No. 99—No damage.
108	Cup type goggle 2 mm. Polycarbonate lens	10th shot same place as No. 99—No damage.
109	Cup type goggle 2 mm. Polycarbonate lens	11th shot same place as No. 99—No damage.
110	Cup type goggle 2 mm. Polycarbonate lens	12th shot same place as No. 99—No damage.

It will be noticed that the first shot broke the lens. This is the only occasion on which a piece of this 2 mm. polycarbonate material was broken and it is not possible to give any reason for its failure in this hastily constructed prototype. It may have been faulty material or it may have been damaged in cutting or mounting. The other lenses followed the usual pattern of all these tests and withstood 12 blows in the centre without cracking, breaking or being penetrated.

Impact Testing at 500 feet per second

28. When it was evident that the polycarbonate material would withstand the impact test at 390 feet per second if the thickness were 2 mm. or approximately 0.080" we decided to test it again at a velocity of 500 feet per second. We began by testing a 2" diameter circle on the lens impact rig described in our Second Report and the results are given in Table VIII.

TABLE VIII

Impact Test in Lens Rig. Projectile velocity 500 feet per second		
Serial No.	Type of Lens	Remarks
111	2 mm. thick Polycarbonate	1st shot—no penetration, fracture or cracking. Lens indented.
112	2 mm. thick Polycarbonate	2nd shot adjacent No. 111. No penetration, fracture or cracking. Lens indented.
113	2 mm. thick Polycarbonate	3rd shot same place as No. 112. Lens penetrated.

Even with a test velocity of 500 feet per second the 2 mm. lens was only penetrated by the 3rd shot, each shot having been virtually in the same place on the lens.

29. A visor type goggle was then constructed and tested in the goggle testing rig using a projectile velocity of 500 feet per second. The results are given in Table IX.

TABLE IX

Impact Test in Goggle Rig. Projectile velocity 500 feet per second		
Serial No.	Type of Protection	Remarks
114	Visor type goggle. 2 mm. Polycarbonate	One shot right eye. No penetration, cracking or fracture.
115	Visor type goggle. 2 mm. Polycarbonate	2nd shot same place as No. 114. Lens penetrated.
116	Visor type goggle. 2 mm. Polycarbonate	One shot left eye. No penetration, cracking or fracture. (N.B. The left eye on this visor had already withstood 13 shots at 390 feet per second.)

It appears that the impact strength of the visor type goggles constructed with one 2 mm. thickness of this polycarbonate material is in excess of our test even when using a projectile velocity of 500 feet per second.

30. Finally we tested the polycarbonate screen in the goggle rig against the velocity of 500 feet per second and the results are given in Table X.

TABLE X

Impact Test in Goggle Rig. Projectile velocity 500 feet per second		
Serial No.	Type of Protection	Remarks
117	Face screen 2 mm. thick Polycarbonate	One shot right eye. No penetration, cracking or fracture. (N.B. The left eye of this screen had already withstood 13 shots at 390 feet per second.)
118	Face screen 2 mm. thick Polycarbonate	Second shot same place as No. 117. Side broke off screen.

It appears that the screen is also capable of withstanding the test with a projectile velocity of 500 feet per second. It should be noticed that both the visor type goggle and the face screen which were tested at 500 feet per second had already been tested at 390 feet per second. They were, therefore, not new material and the higher velocity test was performed on material which had already been strained by severe testing at the lower velocity. It would, therefore, be expected that new material would show better results at the higher velocity. Unfortunately no further specimens were available at the time of testing.

31. To conclude this series of tests on the polycarbonate material a hot ball test was applied (the ball penetrating in 17 seconds) and a needle test was performed on a 2" diameter circle of the material. The results of this latter test are given in Table XI.

TABLE XI

Needle Test		
Serial No.	Type of Lens	Remarks
119	2 mm. Polycarbonate	Needle set 0.010" clear of lens. No cracking or fracture. Lens indented.
120	2 mm. Polycarbonate	Needle set to remote face of lens. No cracking or fracture. Lens first penetrated.

The Face Screen

32. The polycarbonate material could be used as a single layer of 2 mm. thickness in cup goggles or in a similar form in visor type goggles. The lenses would have to be cut from extruded sheet material, however, and this has not been done because the surface of the extruded sheets is not optically perfect. The material has, however, been used to make face screens because these screens are moulded and this process gives a much better surface finish. It has also been found possible to re-polish the screens after they have become scratched in use.

CONCLUSIONS

33. (1) That plastic material to be used for lenses should be examined for strain.
- (2) That no strained material should be used for lenses.
- (3) That the presence of liquids on the front or back faces of the double lens appeared to have no effect on the impact value.
- (4) That a continuous film of liquid between the two parts of the double lens significantly weakened the lens to impact.
- (5) That a double lens consisting of 0.080"/0.080" Celastoid is as good as the earlier 0.050"/0.080" Celastoid lens but requires a special retaining ring with a long enough thread.
- (6) That the thermoplastic polycarbonate material tested withstands impact tests up to 500 feet per second.
- (7) That cup type goggles and visor type goggles can be fitted with this polycarbonate material and will withstand the tests.
- (8) That the extruded sheet polycarbonate material does not yet possess a sufficiently good surface for use as a lens although work is still proceeding on this aspect of the matter.
- (9) That moulded polycarbonate material possesses a surface which may be used as a lens.
- (10) That a suitable face screen can be made using this polycarbonate material as lens.
- (11) That it is possible to re-polish screens made from polycarbonate material.

ACKNOWLEDGMENTS

34. We are indebted to Mr. Livermore of the Midland Motor Cylinder Company Limited for facilities for practical work; to the Directors of B.S.A. (Guns) Limited for the prototype air rifles; to British Celanese Limited for lens specimens; to Mr. C. T. Knott of William Stephens Limited for his interest and assistance in the work and to the Directors of William Stephens Limited for many of the devices which we have tested. Without all this assistance we could not have done the work.

(Signed) A. W. BUSHELL
W. B. LAWRIE

APPENDIX VI

CONTENTS

	Page
Fifth Interim Report of the Sub-Committee of the Joint Advisory Committee on Foundry Goggles	137
Membership of the Sub-Committee of the Joint Advisory Committee on Foundry Goggles	137
INTRODUCTION	138
IMPACT TESTS	139
RESULTS OF IMPACT TESTS	139
CONCLUSIONS	139
ACKNOWLEDGMENTS	140
TABLES	141

**FIFTH INTERIM REPORT OF THE SUB-COMMITTEE OF
THE JOINT ADVISORY COMMITTEE ON FOUNDRY GOGGLES**

Members of Sub-Committee

Mr. A. W. Bushell

Mr. W. B. Lawrie, M.B.E., M.Sc., F.R.M.S., A.I.M.

- (2) When a glass lens is placed between the double acetate lens described in our earlier work, the impact value of the whole lens is so improved that it will withstand the impact of a $\frac{1}{4}$ inch diameter steel ball moving at 500 feet per second.
- (3) When a glass lens is placed in front of a single acetate lens which is 0.080" thick the impact value of the whole lens is so improved that it will withstand the impact of a $\frac{1}{4}$ inch steel ball moving at 500 feet per second.
- (4) When a glass lens is placed in front of a polycarbonate lens, 0.060" thick, the whole lens will withstand the impact of a $\frac{1}{4}$ inch diameter steel ball moving at 500 feet per second.
- (5) The glass is always broken on impact and so it must be placed between two plastic lenses (to contain the fragments) or in front of one plastic lens (so that the plastic will protect against the flying fragments of broken glass).
- (6) The glass lens must never be placed in the goggle so that it is adjacent to the eye of the wearer, because if such a multiple lens were broken by impact the fragments of glass would be driven at speed towards the unprotected eye.
- (7) It would seem desirable to construct goggle frames so that the glass lens could not be put on the wrong side of the plastic lens.
- (8) The glass and plastic lenses were satisfactory against molten metal.

ACKNOWLEDGMENTS

11. We are indebted to Mr. Livermore of the Midland Motor Cylinder Co. Ltd. for facilities for practical work; to the directors of B.S.A. (Guns) Ltd. for the prototype air rifles; to British Celanese Ltd. for lens specimens; to Mr. C. T. Knott of William Stephens Ltd. for his interest and assistance in the work; and to the Directors of William Stephens Ltd. for the devices which we have tested. We could not have done the work without this assistance.

(Signed) A. W. BUSHELL
W. B. LAWRIE

TABLE I

Impact tests with $\frac{1}{2}$ inch steel ball at 500 feet per second on glass and plastic lenses mounted in cup type goggles.

Serial No.	Type of Lens*	Remarks
1	0.050" acetate/24 oz. glass/0.080" acetate	Glass shattered. No penetration. No damage to plastic lenses.
2	0.050" acetate/24 oz. glass/0.080" acetate	Glass shattered. No penetration. No damage to plastic lenses.
3	0.050" acetate/24 oz. glass/0.080" acetate	Glass shattered. No penetration. No damage to plastic lenses.
4	0.050" acetate/24 oz. glass/0.080" acetate	Glass shattered. No penetration. No damage to plastic lenses.
5	0.050" acetate/24 oz. glass/0.080" acetate	Glass shattered. No penetration. No damage to plastic lenses.
6	0.050" acetate/24 oz. glass/0.080" acetate	Glass shattered. No penetration. No damage to plastic lenses.
7	0.050" acetate/toughened glass/0.080" acetate	Glass shattered. No penetration. No damage to plastic lenses.
8	0.050" acetate/toughened glass/0.080" acetate	Glass shattered. No penetration. No damage to plastic lenses.
9	0.050" acetate/toughened glass/0.080" acetate	Glass shattered. No penetration. No damage to plastic lenses.
10	0.050" acetate/toughened glass/0.080" acetate	Glass shattered. No penetration. No damage to plastic lenses.
11	0.050" acetate/toughened glass/0.080" acetate	Glass shattered. No penetration. No damage to plastic lenses.
12	0.050" acetate/toughened glass/0.080" acetate	Glass shattered. No penetration. No damage to plastic lenses.
13	0.050" acetate/laminated glass/0.080" acetate	Glass shattered. No penetration. No damage to plastic lenses.
14	0.050" acetate/laminated glass/0.080" acetate	Glass shattered. No penetration. No damage to plastic lenses.
15	0.050" acetate/laminated glass/0.080" acetate	Glass shattered. No penetration. No damage to plastic lenses.
16	0.050" acetate/laminated glass/0.080" acetate	Glass shattered. No penetration. No damage to plastic lenses.
17	0.050" acetate/laminated glass/0.080" acetate	Glass shattered. No penetration. No damage to plastic lenses.
18	0.050" acetate/laminated glass/0.080" acetate	Glass shattered. No penetration. No damage to plastic lenses.
19	24 oz. glass/0.080" acetate	Glass shattered. No penetration. No damage to plastic lenses.
20	24 oz. glass/0.080" acetate	Glass shattered. No penetration. No damage to plastic lenses.
21	24 oz. glass/0.080" acetate	Glass shattered. No penetration. No damage to plastic lenses.

* The front lens, which received the blow of the projectile, is the first lens specified in this column, and the back lens nearest to the eye, is the last lens specified.

- (2) When a glass lens is placed between the double acetate lens described in our earlier work, the impact value of the whole lens is so improved that it will withstand the impact of a $\frac{1}{4}$ inch diameter steel ball moving at 500 feet per second.
- (3) When a glass lens is placed in front of a single acetate lens which is 0.080" thick the impact value of the whole lens is so improved that it will withstand the impact of a $\frac{1}{4}$ inch steel ball moving at 500 feet per second.
- (4) When a glass lens is placed in front of a polycarbonate lens, 0.060" thick, the whole lens will withstand the impact of a $\frac{1}{4}$ inch diameter steel ball moving at 500 feet per second.
- (5) The glass is always broken on impact and so it must be placed between two plastic lenses (to contain the fragments) or in front of one plastic lens (so that the plastic will protect against the flying fragments of broken glass).
- (6) The glass lens must never be placed in the goggle so that it is adjacent to the eye of the wearer, because if such a multiple lens were broken by impact the fragments of glass would be driven at speed towards the unprotected eye.
- (7) It would seem desirable to construct goggle frames so that the glass lens could not be put on the wrong side of the plastic lens.
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(Signed) A. W. BUSHELL
W. B. LAWRIE

TABLE I

Impact tests with $\frac{1}{4}$ inch steel ball at 500 feet per second on glass and plastic lenses mounted in cup type goggles.

Serial No.	Type of Lens*	Remarks
1	0.050" acetate/24 oz. glass/0.080" acetate	Glass shattered. No penetration. No damage to plastic lenses.
2	0.050" acetate/24 oz. glass/0.080" acetate	Glass shattered. No penetration. No damage to plastic lenses.
3	0.050" acetate/24 oz. glass/0.080" acetate	Glass shattered. No penetration. No damage to plastic lenses.
4	0.050" acetate/24 oz. glass/0.080" acetate	Glass shattered. No penetration. No damage to plastic lenses.
5	0.050" acetate/24 oz. glass/0.080" acetate	Glass shattered. No penetration. No damage to plastic lenses.
6	0.050" acetate/24 oz. glass/0.080" acetate	Glass shattered. No penetration. No damage to plastic lenses.
7	0.050" acetate/toughened glass/0.080" acetate	Glass shattered. No penetration. No damage to plastic lenses.
8	0.050" acetate/toughened glass/0.080" acetate	Glass shattered. No penetration. No damage to plastic lenses.
9	0.050" acetate/toughened glass/0.080" acetate	Glass shattered. No penetration. No damage to plastic lenses.
10	0.050" acetate/toughened glass/0.080" acetate	Glass shattered. No penetration. No damage to plastic lenses.
11	0.050" acetate/toughened glass/0.080" acetate	Glass shattered. No penetration. No damage to plastic lenses.
12	0.050" acetate/toughened glass/0.080" acetate	Glass shattered. No penetration. No damage to plastic lenses.
13	0.050" acetate/laminated glass/0.080" acetate	Glass shattered. No penetration. No damage to plastic lenses.
14	0.050" acetate/laminated glass/0.080" acetate	Glass shattered. No penetration. No damage to plastic lenses.
15	0.050" acetate/laminated glass/0.080" acetate	Glass shattered. No penetration. No damage to plastic lenses.
16	0.050" acetate/laminated glass/0.080" acetate	Glass shattered. No penetration. No damage to plastic lenses.
17	0.050" acetate/laminated glass/0.080" acetate	Glass shattered. No penetration. No damage to plastic lenses.
18	0.050" acetate/laminated glass/0.080" acetate	Glass shattered. No penetration. No damage to plastic lenses.
19	24 oz. glass/0.080" acetate	Glass shattered. No penetration. No damage to plastic lenses.
20	24 oz. glass/0.080" acetate	Glass shattered. No penetration. No damage to plastic lenses.
21	24 oz. glass/0.080" acetate	Glass shattered. No penetration. No damage to plastic lenses.

* The front lens, which received the blow of the projectile, is the first lens specified in this column, and the back lens nearest to the eye, is the last lens specified.

TABLE I (contd.)

Impact tests with $\frac{1}{2}$ inch steel ball at 500 feet per second on glass and plastic lenses mounted in cup type goggles.

Serial No.	Type of Lens*	Remarks
22	24 oz. glass/0.080" acetate	Glass shattered. No penetration. No damage to plastic lenses.
23	24 oz. glass/0.080" acetate	Glass shattered. No penetration. No damage to plastic lenses.
24	24 oz. glass/0.080" acetate	Glass shattered. No penetration. No damage to plastic lenses.
25	Toughened glass/0.080" acetate	Glass shattered. No penetration. No damage to plastic lenses.
26	Toughened glass/0.080" acetate	Glass shattered. No penetration. No damage to plastic lenses.
27	Toughened glass/0.080" acetate	Glass shattered. No penetration. No damage to plastic lenses.
28	Toughened glass/0.080" acetate	Glass shattered. No penetration. No damage to plastic lenses.
29	Toughened glass/0.080" acetate	Glass shattered. No penetration. No damage to plastic lenses.
30	Toughened glass/0.080" acetate	Glass shattered. No penetration. No damage to plastic lenses.
31	Laminated glass/0.080" acetate	Glass shattered. No penetration. No damage to plastic lenses.
32	Laminated glass/0.080" acetate	Glass shattered. No penetration. No damage to plastic lenses.
33	Laminated glass/0.080" acetate	Glass shattered. No penetration. No damage to plastic lenses.
34	Laminated glass/0.080" acetate	Glass shattered. No penetration. No damage to plastic lenses.
35	Laminated glass/0.080" acetate	Glass shattered. No penetration. No damage to plastic lenses.
36	Laminated glass/0.080" acetate	Glass shattered. No penetration. No damage to plastic lenses.
37	24 oz. glass/0.060" polycarbonate	Glass shattered. No penetration. No damage to plastic lenses.
38	24 oz. glass/0.060" polycarbonate	Glass shattered. No penetration. No damage to plastic lenses.
39	Toughened glass/0.060" polycarbonate	Glass shattered. No penetration. No damage to plastic lenses.
40	Toughened glass/0.060" polycarbonate	Glass shattered. No penetration. No damage to plastic lenses.
41	Laminated glass/0.060" polycarbonate	Glass shattered. No penetration. No damage to plastic lenses.
42	Laminated glass/0.060" polycarbonate	Glass shattered. No penetration. No damage to plastic lenses.

* The front lens, which received the blow of the projectile, is the first lens specified in this column, and the back lens nearest to the eye, is the last lens specified.

TABLE II

Impact tests with $\frac{1}{4}$ inch steel ball at 500 feet per second on glass and plastic lenses mounted in cup type goggles.

Serial No.	Type of Lens*	Remarks
43	0.050" acetate/24 oz. glass/0.080" acetate	Front acetate lens broken, glass shattered, back acetate lens cracked. No penetration by projectile.
44	0.050" acetate/24 oz. glass/0.080" acetate	Glass shattered. No damage to plastic lenses. No penetration.
45	0.050" acetate/toughened glass/0.080" acetate	Glass shattered. No damage to plastic lenses. No penetration.
46	0.050" acetate/laminated glass/0.080" acetate	Front acetate lens just penetrated, glass broken, back acetate lens undamaged. Ball lodged in laminated lens and front lens.
47	0.050" acetate/laminated glass/0.080" acetate	Glass shattered. No damage to plastic lenses. No penetration.
48	24 oz. glass/0.080" acetate	Glass shattered. No damage to plastic lenses. No penetration.
49	Toughened glass/0.080" acetate	Glass shattered. No damage to plastic lenses. No penetration.
50	Laminated glass/0.080" acetate	Glass shattered. No damage to plastic lenses. No penetration.
51	24 oz. glass/0.060" polycarbonate	Glass shattered. No damage to plastic lenses. No penetration.
52	Toughened glass/0.060" polycarbonate	Glass shattered. No damage to plastic lenses. No penetration.
53	Laminated glass/0.060" polycarbonate	Glass shattered. No damage to plastic lenses. No penetration.

* The front lens, which received the blow of the projectile, is the first lens specified in this column, and the back lens nearest to the eye, is the last lens specified.

APPENDIX VII

References

1. Final Report on the American Society of Safety Engineers' Research Project—Plastic Eye Protectors.
2. First Interim Report of the Sub-Committee of the Joint Advisory Committee on Foundry Goggles—Foundry Trade Journal, March 6th, March 20th and April 3rd, 1958. (See Appendix I).
3. Second Interim Report of the Sub-Committee of the Joint Advisory Committee on Foundry Goggles—Foundry Trade Journal, May 21st, 1959. (See Appendix III).
4. Third Interim Report of the Sub-Committee of the Joint Advisory Committee on Foundry Goggles—Foundry Trade Journal, September 8th, 1960. (See Appendix IV).
5. Reid, A. M.—"A Laboratory Ballistic Trial of Goggle Lenses"—Foundry Trade Journal, April 3rd, 1958. (See Appendix II).
6. British Standard 2092: 1962, British Standards Institution, London.
7. British Standard 1729: 1952, British Standards Institution, London.
8. British Standard 679: 1959, British Standards Institution, London.
9. British Standard 2724: 1956, British Standards Institution, London.



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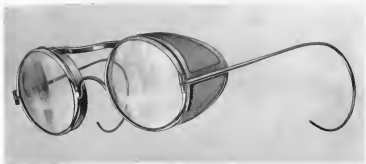


Fig. 1. Spectacles



Fig. 2. Cup Type Goggles



Fig. 3. Visor Type Goggles



Fig. 4. Face Screen



Fig. 5. Testing Machine

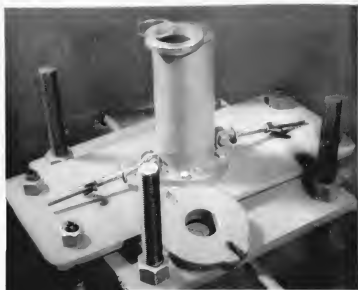


Fig. 6. Testing Machine
Showing method of mounting specimen above stop platform



Fig. 7

Ejector Heads, Retaining Rings, Spacing Rings, Clamps and Guard

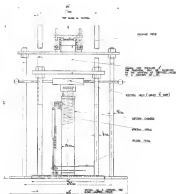
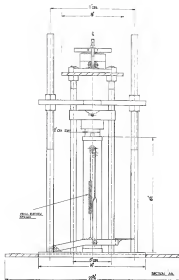


Fig. 31. Testing machine (see Fig. 31)



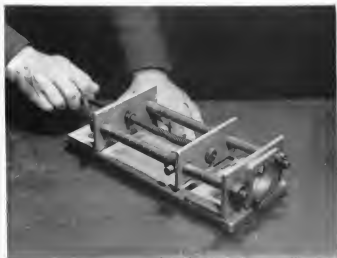
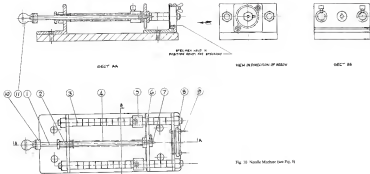


Fig. 9. Needle Machine



GRAPH I

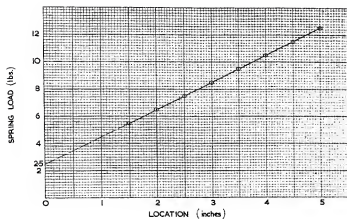


Fig. 11

GRAPH II.

$$v = 3.1L + 2.3 \quad \left(\begin{array}{l} v - \text{velocity ft./sec.} \\ L - \text{location - inches} \end{array} \right)$$

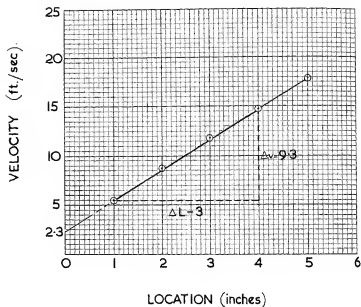


Fig. 12



Fig. 14
Air rifle rig with weapon and guard in position

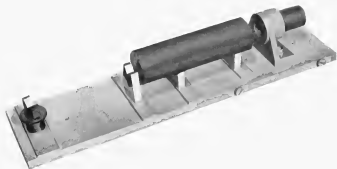


Fig. 15
Air rifle rig—weapon and guard removed

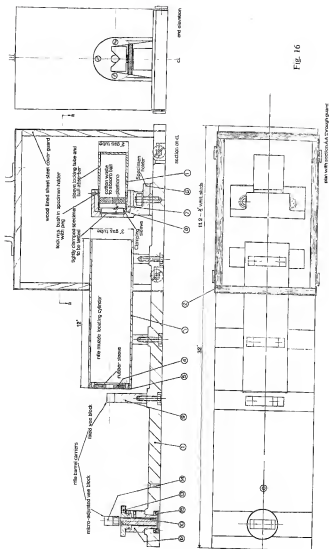
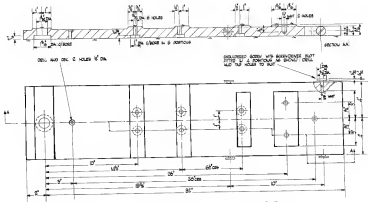
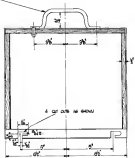
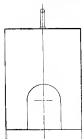


Fig. 16

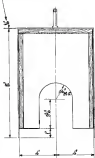


1/2" dia. pin if load sent to room frame
 and secured at beam ends using
 1/2" dia. pin and nut.

1/2" dia. pin if load sent to room frame
 and secured at beam ends using
 1/2" dia. pin and nut.



SECTION ON A-A

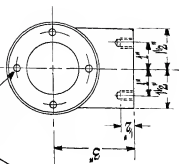
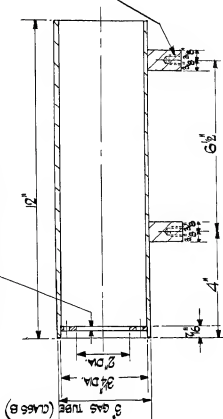


SECTION ON B-B

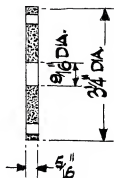
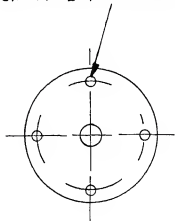
1/8" THICK MS. DISC SPIGOTED IN
GAS TUBE AND TACK WELDED

DRILL AND TAP 2 HOLES $\frac{3}{8}$ " WHIT.
IN EACH M.S. FOOT.

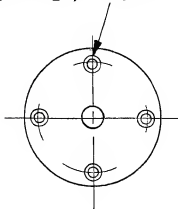
DRILL AND TAP 4 HOLES
1/4" DIA. EQUI-SPACED ON A
2 3/4" P.C. DIA.

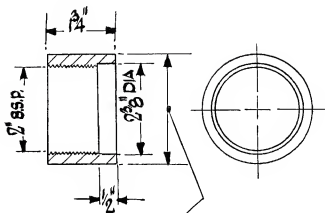
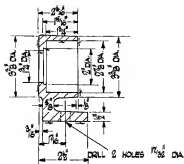
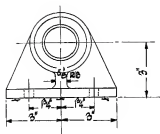


4 HOLES $\frac{1}{4}"$ DIA. EQUI-SPACED
ON A $2\frac{3}{4}"$ P.C. DIA.

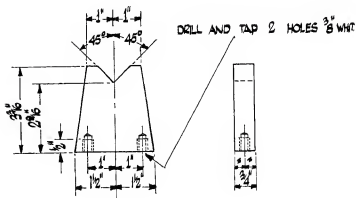
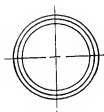
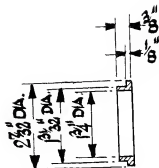


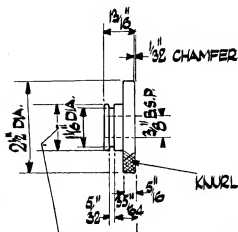
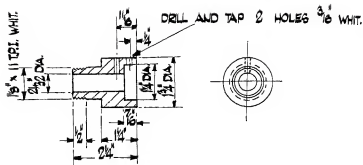
DRILL AND CGK. 4 HOLES TO SUIT
 $\frac{1}{4}"$ WHIT. CGK. SCREWS EQUI-SPACED
ON A $2\frac{3}{4}"$ RC. DIA.



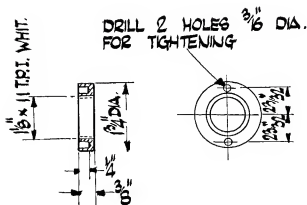
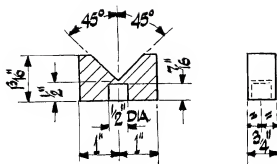


MACHINE THIS DIA. TO SUIT $2\frac{7}{8}$ " DIA.
HOLE IN SPECIMEN HOLDER :
(LIGHT TAP FIT)





MACHINE THIS DIA. TO SUIT $\frac{1}{4}$ " DIA. HOLE IN
ADJUSTING SCREW HOLDER (RUNNING FIT)



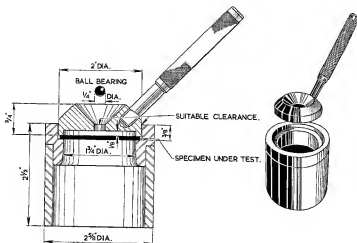


Fig. 18. Equipment for burning tests

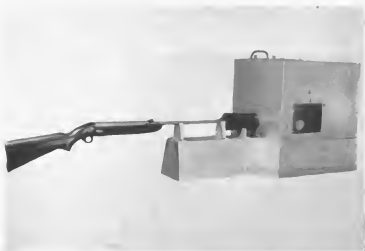


Fig. 19

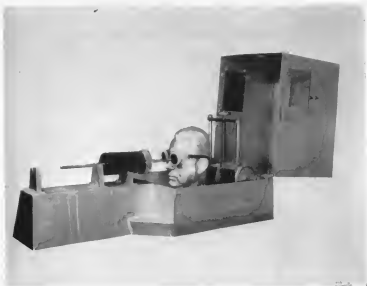


Fig. 20

122a



Fig. 21

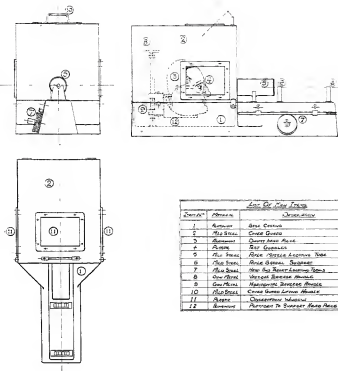


Fig. 22

<i>List of Parts</i>		
<i>Number</i>	<i>Material</i>	<i>Description</i>
1	Aluminum	Base Cover
2	Aluminum	Base Cover
3	Aluminum	Quartz Lens Plate
4	Aluminum	Base Cover
5	Aluminum	Base Cover Lens Plate
6	Aluminum	Base Cover Lens Plate
7	Aluminum	Base Cover Lens Plate
8	Aluminum	Base Cover Lens Plate
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10	Aluminum	Base Cover Lens Plate
11	Aluminum	Base Cover Lens Plate
12	Aluminum	Base Cover Lens Plate

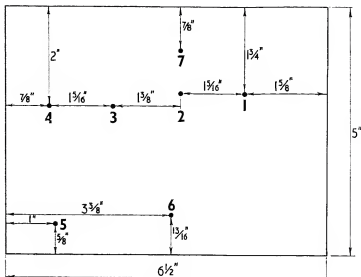


Fig. 23

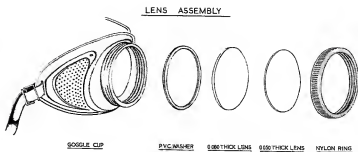


Fig. 24